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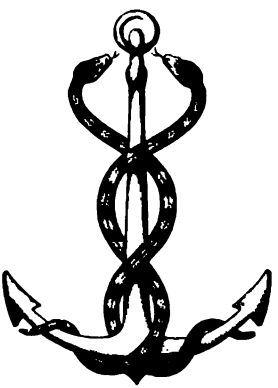
MANUAL OF BACTERIOLOGY.



NUNQUAM ALIUD NATURA, ALIUD SAPIENTIA DICIT.

MANUAL

OF

BACTERIOLOGY

BY

ROBERT MUIR, M.A., M.D., F.R.C.P.Ed.

LECTURER ON PATHOLOGICAL BACTERIOLOGY, AND SENIOR ASSISTANT TO THE PROFESSOR OF PATHOLOGY, UNIVERSITY OF EDINBURGH; PATHOLOGIST, EDINBURGH ROYAL INFIRMARY.

AND

JAMES RITCHIE, M.A., M.D., B.Sc.

LECTURER IN PATHOLOGY, UNIVERSITY OF OXFORD.

WITH ONE HUNDRED AND EIGHT ILLUSTRATIONS.

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PREFACE.

THE science of Bacteriology has, within recent years, become so extensive, that in treating the subject in a book of this size we are necessarily restricted to some special departments, unless the description is to be of a superficial character. Accordingly, as this work is intended primarily for students and practitioners of medicine, only those bacteria which are associated with disease in the human subject have been considered. We have made it a chief endeavour to render the work of practical utility for beginners, and, in the account of the more important methods, have given elementary details which our experience in the practical teaching of the subject has shown to be necessary.

In the systematic description of the various bacteria, an attempt has been made to bring into prominence the evidence of their having an etiological relationship to the corresponding diseases, to point out the general laws governing their action as producers of disease, and to consider the effects in particular instances of various modifying circumstances. Much research on certain subjects is so recent that conclusions on many points must necessarily

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be of a tentative character. We have, therefore, in our statement of results aimed at drawing a distinction between what is proved and what is only probable.

In an Appendix we have treated of four diseases; in two of these the causal organism is not a bacterium, whilst in the other two its nature is not yet determined. These diseases have been included on account of their own importance and that of the pathological processes which they illustrate.

Our best thanks are due to Professor Greenfield for his kind advice in connection with certain parts of the work. We have also great pleasure in acknowledging our indebtedness to Dr. Patrick Manson, who kindly lent us the negatives or preparations from which Figs. 102-107 have been executed.

As we are convinced that to any one engaged in practical study, photographs and photomicrographs supply the most useful and exact information, we have used these almost exclusively in illustration of the systematic description. These have been executed in the Pathological Laboratory of the University of Edinburgh by Mr. Richard Muir. The line drawings were prepared for us by Mr. Alfred Robinson, of the University Museum, Oxford.

To the volume is appended a short bibliography, which, while having no pretension to completeness, will, we hope, be of use in putting those who desire further information on the track of the principal papers which have been published on each of the subjects considered.

June 1897.

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MANUAL OF BACTERIOLOGY.

MANUAL OF BACTERIOLOGY.

CHAPTER I.

GENERAL MORPHOLOGY AND BIOLOGY.

Introductory.—At the bottom of the scale of living things there exists a group of organisms to which the name of bacteria is usually applied. These are apparently of very simple structure and may be subdivided into two sub-groups, a lower and simpler and a higher and better developed.

The *lower forms* are the more numerous, and consist of minute unicellular masses of protoplasm devoid of chlorophyll, which multiply by simple fission. Some are motile, others non-motile. Their minuteness may be judged of by the fact that in one direction at least they usually do not measure more than 1 μ ($\frac{1}{25000}$ inch). These forms can be classified according to their shapes into three main groups—(1) A group in which the shape is globular. The members of this are called *cocci*. (2) A group in which the shape is that of a straight rod—the proportion of the length to the breadth of the rod varying greatly among the different members. These are called *bacilli*. (3) A group in which the shape is that of a curved or spiral rod. These are called *spirilla*. The fuller description of the characters of these

groups will be more conveniently taken later (p. 15). In some cases, especially among the bacilli, there may occur under certain circumstances changes in the protoplasm whereby a resting stage or spore is formed.

The *higher forms* show advance on the lower along two lines. (1) On the one hand they consist of filaments made up of simple elements such as occur in the lower forms. These filaments may be more or less septate, may be provided with a sheath, and may show branching either true or false. The minute structure of the elements comprising these filaments is analogous to that of the lower forms. Their size, however, is often somewhat greater. The lower forms sometimes occur in filaments, but here every member of the filament is independent, while in the higher forms there seems to be a certain interdependence among the individual elements. For instance, growth may occur only at one end of a filament, the other forming an attachment to some fixed object. (2) The higher forms, moreover, present this further development that in certain cases the protoplasm of some of the elements may be set apart for the reproduction of new individuals.

Terminology.—The term bacterium of course in strictness only refers to the rod-shaped varieties of the group, but as it has given the name bacteriology to the science which deals with the whole group, it is convenient to apply it to all the members of the latter, and to reserve the term bacillus for the rod-shaped varieties. Other general words, such as germ, microbe, micro-organism, are often used as synonymous with bacterium, though, strictly, they include the smallest organisms of the animal kingdom.

While no living organisms lower than the bacteria are known, the upper limits of the group are difficult to define, and it is further impossible in the present state of our knowledge to give other than a provisional classification of the forms which all recognise to be bacteria. The division into lower and higher forms, however, is fairly well marked, and we shall therefore refer to the former as the lower bacteria, and to the latter as the higher bacteria.

Morphological Relations.—The relations of the bacteria to the animal kingdom on the one hand and to the vegetable on the other constitute a somewhat difficult question. The occurrence of spore formation among the lower forms is analogous to what takes place in certain unicellular organisms—the flagellata—which, though some of the members contain chlorophyll, are usually ranked in the animal kingdom with the protozoa. On the other hand, the fact that many bacteria can derive the carbon they require for their nourishment from tartrates and their nitrogen from ammonia or its salts, makes it natural that they should be ranked in the vegetable kingdom with other non-chlorophyllous plants as fungi. Such an association is further borne out by the fact that while the higher fungi present many analogies with the higher algæ and have probably descended from them, there is a group of lower algæ the members of which morphologically are analogous to the bacteria. These algæ are unicellular masses of protoplasm, having generally the same shapes as the bacteria, and largely multiply by fission. The protoplasm differs from that of the bacteria in containing chlorophyll and also another blue-green pigment called phycocyan. From the morphological resemblances between the algæ and the bacteria, and from the fact that fission plays a predominant part in the multiplication of both, they have been grouped together in one class as the Schizophyta or splitting plants (German, Spaltpflanzen). And of the two divisions forming these Schizophyta the splitting algæ are denominated the schizophyceæ (German, Spaltalgen), while the bacteria or splitting fungi are called the schizomycetes (German, Spaltpilzen). The bacteria are, therefore, in proper scientific nomenclature, to be spoken of as the schizomycetes. Certain bacteria which have been described as containing chlorophyll ought probably to be grouped among the schizophyceæ.

General Morphology of the Bacteria.

The Structure of the Bacterial Cell.—On account of the minuteness of bacteria the investigation of their structure is attended with great difficulty. When examined under the microscope, in their natural condition in, say, water, they appear merely as colourless refractile bodies of the different shapes named. Spore formation and motility, when these exist, can also be observed, but little else can be made out. For their proper investigation advantage is always taken of the fact of their affinities for various dyes, especially those which are usually chosen as good stains for the nuclei of animal cells. Certain points have thus been

determined. The bacterial cell consists of a sharply contoured mass of protoplasm which reacts to, especially basic, aniline dyes like the nucleus of an animal cell. From this fact it has been deduced that there is probably a close relationship between the protoplasm of bacteria and the chromatin of the nuclear protoplasm. To speak generally, a healthy bacterium when stained presents the appearance of a finely granular or almost homogeneous structure. The protoplasm of the bacterial cell is surrounded by an envelope which is probably of a gelatinous nature, and which can in some cases be demonstrated by overstaining a specimen with some of the aniline dyes, when it will appear as a halo round the bacterium. This envelope may sometimes be seen to be of considerable thickness. Its innermost layer is probably of a denser consistence, and sharply contours the contained protoplasm, giving the latter the appearance of being surrounded by a membrane. It is only, however, in some of the higher forms that a true membrane occurs. Sometimes the outer margin of the envelope is sharply defined, in which case the bacterium appears to have a distinct capsule, and is known as a capsulated bacterium (*vide* Fig. 1, No. 4; and Fig. 50). The cohesion of bacteria into masses depends largely on the character of the envelope. If the latter is glutinous, then a large mass of the same species may occur formed of individual bacteria embedded in what appears to be a mass of jelly. When this occurs, it is known as a zoogloœa mass. On the other hand, if the envelope has not this cohesive property the separation of individuals may easily take place, especially in a fluid medium in which they may float entirely free from one another. The bacterial envelope does not, as in the case of most vegetable cells, contain cellulose.

Motility.—As has been stated, many bacteria are motile. Motility in a species is associated with the possession of wavy thread-like appendages called flagella, which for their demonstration require the application of special staining methods (*vide* Fig. 1, No. 12; and Fig. 78). They have been shown to occur in many bacilli and spirilla, but only in two

species of cocci. They may be several times the length of the bacterium, and may be at one or both extremities or all round. When terminal they may occur singly or there may be several. It is doubtful whether, as in many algæ, they are prolongations of the protoplasm through the envelope, or whether they are merely appendages of the latter, in which case some have been inclined to doubt whether they are really organs of locomotion or not. For the present purpose it is sufficient to state that while flagella have been observed in all the lower bacteria which are motile, except perhaps in some special spiral forms, and not in the non-motile forms, some motile forms of the higher bacteria are known in which motility is not associated with the possession of special organs, but is probably due to contractility of the protoplasm itself.

Multiplication.—When a bacterial cell is placed in favourable surroundings it multiplies; as has been said, this, in the great majority of cases, takes place by simple fission. In this process a constriction appears in the middle and a transverse unstained line develops across the protoplasm at that point. The process goes on till two individuals can be recognised, which may remain for a time attached to one another, or become separate, according to the character of the envelope, as already explained. In most bacteria growth and multiplication go on with great rapidity. A bacterium may reach maturity and divide in from twenty minutes to half an hour. In the latter case a simple calculation will show that, at the end of twenty-four hours, from one individual 17,000,000 similar individuals will be produced. As shown by the results of artificial cultivation, others, such as the tubercle bacillus, multiply much more slowly. When bacteria are placed in unfavourable conditions as regards food, etc., growth and multiplication take place with difficulty. In the great majority of cases this is evidenced by changes in the appearance of the protoplasm. Instead of its maintaining the regularity of shape seen in healthy bacteria, various aberrant appearances are presented. This occurs especially in the rod-shaped

varieties, where flask-shaped or dumb-bell-shaped individuals may be seen. The regularity in structure and size is quite lost. The appearance of the protoplasm also is often altered. Instead of, as formerly, staining well, it does not stain readily, and may have a uniformly pale, homogeneous appearance, while in an old culture only a small proportion of the bacteria may stain at all. Sometimes a degenerated bacterium, on the other hand, contains intensely stained granules or globules which may be of large size. Such aberrant and degenerate appearances are referred to as *involution forms*. That these forms really betoken degenerative changes is shown by the fact that, on their being again transferred to favourable conditions, only slight growth at first takes place. Many individuals have undoubtedly died, and the remainder which live and develop into typical forms may sometimes have lost some of their properties.

Spore Formation.—In certain species of bacteria, and under certain circumstances, changes take place in the protoplasm which result in the formation of bodies called spores, to which the vital activities of the original bacteria are transferred. Spore formation occurs chiefly among the bacilli and in some spirilla. Its commencement in a bacterium is indicated by the appearance in the protoplasm of a minute highly refractile granule unstained by the ordinary methods. This increases in size, and assumes a round, oval, or short rod-shaped form, always shorter but often broader than the original bacterium. In the process of spore formation the rest of the bacterial protoplasm may remain unchanged in appearance and staining power for a considerable time (*e.g.*, B. tetani), or, on the other hand, it may soon lose its power of staining and ultimately disappear, leaving the spore in the remains of the envelope (*e.g.*, B. anthracis). This method of spore formation is called *endogenous*. The spore may appear in the centre of the bacterium, or it may be at one extremity, or a short distance from one extremity (Fig. 1, No. 11). In structure the spore consists of a mass of protoplasm surrounded by a dense membrane. This can be demonstrated by methods which will be described, the

underlying principle of which is the prolonged application of a powerful stain. The membrane is supposed to confer on the spore its characteristic feature, namely, great capacity of resistance to external influences such as heat or noxious chemicals. Koch, for instance, in one series of experiments, found that while the bacillus anthracis in the unspored form was killed by a two minutes' exposure to 1 per cent carbolic acid, spores of the same organism resisted an exposure of from one to fifteen days.

When a spore is placed in suitable surroundings for growth it again assumes the original bacillary or spiral form. The capsule dehisces either longitudinally, or terminally, or transversely. In the last case the dehiscence may be partial, and the new individual may remain for a time attached by its ends to the hinged spore-case, or the dehiscence may be complete, and the bacillus grow with a cap at each end consisting of half the spore-case. Sometimes the spore-case does not dehisce, but is simply absorbed by the developing bacterium.

It is important to note that in the bacteria spore formation is rarely, if ever, to be considered as a method of multiplication. In at least the great majority of cases only one spore is formed from one bacterium, and only one bacterium in the first instance from one spore. Sporulation is to be looked upon as a resting stage of a bacterium, and is to be contrasted with the stage when active multiplication takes place. The latter is usually referred to as the vegetative stage of the bacterium. Regarding the signification of spore formation in bacteria there has been some difference of opinion. According to one view it may be regarded as representing the highest stage in the vital activity of a bacterium. There is thus an alternation between the vegetative and spore stage, the occurrence of the latter being necessary to the maintenance of the species in its greatest vitality. Such a rejuvenescence, as it were, through sporulation, is known in many algæ. In support of this view there are certain facts. In many cases, for instance, spore formation only occurs at temperatures specially

favourable for growth and multiplication. There is often a temperature below which, while vegetative growth still takes place, sporulation will not occur, and in the case of B. anthracis, if it be kept at a temperature above the limit at which it grows best, not only are no spores formed, but the species may lose the power of sporulation. Furthermore, in the case of bacteria preferring the presence of oxygen for their growth an abundant supply of this gas may favour sporulation. On the other hand, however, most bacteriologists are of opinion that when a bacterium forms a spore, it only does so when its surroundings, especially its food supply, become unfavourable for vegetative growth; it then remains in this condition until it is placed in more suitable surroundings. Such an occurrence would be analogous to what takes place under similar conditions in many of the protozoa. Sporulation can be prevented from taking place for an indefinite time if a bacterium is constantly supplied with fresh food (the other conditions of life being equal). In old growths, where the food supply is exhausted the bacteria have either become spores or have died. Further, a spore will always develop into a vegetative form if placed in a fresh food supply. With regard to the rapid formation of spores when the conditions are favourable for vegetative growth, it must be borne in mind that in such circumstances the conditions may really very quickly become unfavourable for a continuance of growth, for not only will the food supply around the growing bacteria be rapidly exhausted, but we have evidence that in such conditions effete products are excreted which are inimical to the life of the organisms excreting them.

We must note that the tests of a body developed within a bacterium being a spore are (1) its staining reaction, namely, resistance to ordinary staining fluids, but capacity of being stained by the special methods devised for the purpose (*vide* p. 103); (2) the fact that the bacterium containing the spore has higher powers of resistance against inimical conditions than a vegetative form. It is important to bear these tests in mind, as in some of the smaller

bacteria especially, it is very difficult to say whether they spore or not. There may appear in such organisms small unstained spots the significance of which it is very difficult to determine.

The Question of Arthrosporous Bacteria.—It is stated by Hueppe that among certain organisms, *e.g.*, some streptococci, certain individuals may without endogenous sporulation take on a resting stage. These become swollen, stain well with ordinary stains, and they are stated to have higher power of resistance than the other forms, and, further, when vegetative life again occurs it is from them that multiplication takes place. From the fact that there is no new formation within the protoplasm, but that it is the whole of the latter which participates in the change, these individuals have been called *arthrospores*. The existence of such special individuals amongst the lower bacteria is extremely problematical. They have no distinct capsule, and they present no special staining reactions, nor any microscopic features by which they can be certainly recognised, while their alleged increased powers of resistance are very doubtful. All the phenomena noted can be explained by the undoubted fact that in an ordinary growth there is very great variation among the individual organisms in their powers of resistance to external conditions.

Substances occurring in the Protoplasm of Bacteria.—In the bodies of bacteria many substances occur. Some have been described as containing chlorophyll, but these organisms are properly to be classed with the schizophyceæ. Sulphur is found in some of the higher forms, and starch granules are also described as occurring. Many species of bacteria, when growing in masses, are brilliantly coloured. Comparatively few bacteria, however, associated with the production of disease give rise to pigments. In some of the organisms classed as bacteria a pigment named bacteriopurpurin has been observed in the protoplasm, and similar intracellular pigments probably occur in some of the larger forms of the lower bacteria and may occur in the smaller; but here exact observation is a work of great difficulty, and in the majority of the latter it is impossible to determine whether the pigment occurs inside or outside the protoplasm. In many cases, for the free production of pigment abundant oxygen supply is necessary. On the other hand, sometimes, as in the case of *spirillum rubrum*, the pigment

is best formed in the absence of oxygen. Sometimes the faculty of forming it may be lost for a time, if not permanently, by altering the conditions of growth of an organism. Thus, for example, if the B. pyocyaneus be exposed to the temperature of 42° C. for a certain time, it loses its power of producing its bluish pigment. Pigments formed by bacteria often diffuse out into, and colour, the medium for a considerable distance around.

Comparatively little is known of the nature of bacterial pigments. Zopf, who has devoted much attention to the pigments occurring in the lower plants, has found that many of them belong to a group of colouring matters which occur widely in the vegetable and animal kingdoms, viz. the lipochromes. These lipochromes, which get their name from the colouring matter of animal fat, include the colouring matter in the petals of Ranunculaceæ, the yellow pigments of serum and the yolks of eggs, and many bacterial pigments. Among the latter is a lipochrome *carotin*, which is also the pigment in carrots and tomatoes. The lipochromes are characterised by their solubility in chloroform, alcohol, ether, and petroleum, and by their giving indigo-blue crystals with strong sulphuric acid, and a green colour with iodine dissolved in potassium iodide. Though crystalline compounds of these have been obtained, their chemical constitution is entirely unknown and even their percentage composition is disputed.

The Minuter Structure of the Bacterial Protoplasm.—Many attempts have been made to obtain deeper information as to the structure of the bacterial cell, and especially as to its behaviour in division. These have largely turned on the interpretation to be put on certain appearances which have been observed to occur. These appearances are of two kinds. First, under certain circumstances irregular deeply-stained granules are observed in the protoplasm, often, when they occur in a bacillus, giving the latter the appearance of a short chain of cocci. They are often called metachromatic granules (*vide* Fig. 1, No. 16) from the fact that by appropriate procedure they can be stained with one dye, and the protoplasm in which they lie with another; sometimes, when a single stain is used, such as methylene blue, they assume a slightly different tint from the protoplasm. The second appearance which can sometimes be observed is the occurrence of rounded or oval unstained

portions in the bacterial protoplasm. In a bacillus or spirillum there is often such a body at each end, in which case they are frequently called polar granules (*vide* Fig. 1, No. 13) (German, Polkörnchen or Polkörner).

For the demonstration of the metachromatic granules two methods have been advanced. Ernst recommends that a few drops of Löffler's methylene-blue (*vide* p. 97) be placed on a cover-glass preparation and the latter passed backwards and forwards over a Bunsen flame for half a minute after steam begins to rise. The preparation is then washed in water and counter-stained for one to two minutes in watery Bismarck-brown. The granules are here stained blue, the protoplasm brown. Neisser stains a similar preparation in warm carbol-fuchsin, washes with 1 per cent sulphuric acid and counter-stains with Löffler's blue. Here the granules are magenta, the protoplasm blue. The general nature of the granules thus is that they retain the first stain more intensely than the rest of the protoplasm.

The polkörnchen can be demonstrated by the fact that they remain unstained when the bacteria are treated with any of the ordinary stains.

Both the metachromatic granules and the polkörnchen have been looked upon by different observers as spores. Against this view, however, is the fact that growths in which they exist show no higher degree of resistance than growths in which they cannot be observed. Further, they do not react to the strict methods of spore staining. Some have looked upon the metachromatic granules as evidences of the process of division in the bacterial protoplasm, *i.e.*, of a kind of mitosis. If such is the case they ought to be observed in some members of a growth where active multiplication is going on, and this is not so. The conditions in which they occur are in growths where the food material is becoming exhausted, or in growths which have been subjected to unfavourable conditions. Thus they have been observed in bacteria which have been grown for a few days at the most favourable temperature, and thereafter allowed to develop further at less suitable temperatures. It is thus very probable that the occurrence of metachromatic granules in a bacterium indicates the onset of degenerative changes.

With regard to the polkörner we have seen that evidence

of their being spores is lacking. Their development has been attributed by some to a process common in many animal and vegetable cells, and known as *plasmolysis*. To speak generally, when a mass of protoplasm surrounded by a fairly firm envelope of a colloidal nature is placed in a solution containing salts in greater concentration than that in which it has previously been living, then by a process of osmosis the water held in the protoplasm passes out through the membrane, and, the protoplasm retracting from the latter, the appearance of vacuolation is presented. Now in making a dried film for the microscopic examination of bacteria the conditions necessary for the occurrence of this process may be produced, and the appearances of vacuolation and of polkörner may thus be brought about. Plasmolysis in bacteria has recently been pretty extensively investigated,[1] and has been found to occur in some species more readily than in others. We may, however, conclude that such appearances as vacuolation of the bacterial protoplasm and polkörner are either signs of degeneration, like the metachromatic granules, or are artificially produced. All of them are most frequently observed in old or otherwise enfeebled cultures.

Bütschli has published interesting observations on the minute structure of some large sulphur-containing bacteria. These were found to consist of an outer membrane enclosing the protoplasm, which was divided into two parts—an outer protoplasmic network containing bacterio-purpurin, and an inner part, the greater part of the latter being stained blue with hæmatoxylin, more deeply than the outer, in specimens out of which the bacterio-purpurin had been dissolved. In this central part thus stained there were red granules, which Bütschli regards as the metachromatic granules of Ernst. The bacilli in the specimens he examined seem, however, to have been healthy. Bütschli looks upon the outer part of the central body as corresponding to the protoplasm of an ordinary cell, the inner part as corresponding to the nucleus. In one smaller bacterium he found evidence of the former only at the end of the cell. He therefore thinks that the greater part of the bacterial cell may correspond to a nucleus, and that this is surrounded by a thin layer of protoplasm, which in the smaller bacteria probably

[1] Consult Fischer, "Untersuchungen über Bakterien," Berlin, 1894; "Ueber den Bau der Cyanophyceen und Bakterien," Jena, 1897.

escapes notice, unless when it is specially abundant at the ends. This terminal plasma has also been found by Wager in another bacterium. Among the bacteria Bütschli further finds confirmation of his views on the mesh-like structure of protoplasm generally. A bacillus, for instance, he finds consists of four or five more or less square meshes laid end to end, and he gives microphotographs of bacilli presenting such appearances (*vide* Fig. 1, Nos. 15*a* and *b*). With regard to these observations of Bütschli, Fischer holds that the appearances seen were due to plasmolysis, and considers that there is no evidence of differentiation between protoplasm and nucleus in the bacterial cell.

The Chemical Composition of Bacteria.—Some observations have been made on the chemical structure of bacterial protoplasm. Nencki precipitated the bodies of putrefactive bacteria with 2-3 per cent hydrochloric acid, filtered them off, extracted with alcohol and ether, and dissolved the residue with .5 per cent potassium hydrate solution. This solution contained an albumin which was fairly constant in its percentage composition in samples obtained from different mixtures of these bacteria, and which Nencki named mycoprotein; it was soluble in water, acids, and alkalies, insoluble in solutions of neutral salts. To show, however, that albuminoid constituents of bacteria vary, it must be noted that from anthrax spores Nencki obtained an albumin which he calls anthraxprotein, and which differs from mycoprotein in its being insoluble in water, acetic acid, and dilute mineral acids. Both differ from nucleo-albumin, a constituent of the nuclei of higher cells, in containing no phosphorus. Other observers have isolated similar bodies having, however, different percentage compositions from those given by Nencki. According to some recent results the amount of nitrogenous material present varies according to the temperature at which growth has taken place, according to the age of the culture, and also according to the medium used. Besides nitrogenous material, salts of sodium, potassium, magnesium, and phosphorus may be present in the bacterial protoplasm. In certain cases traces of cellulose and also fatty bodies have been isolated. It is probable that the composition of bacteria varies according to the species.

The Classification of Bacteria. — There have been numerous schemes set forth for the classification of bacteria, the fundamental principle running through all of which has been the recognition of the two sub-groups and the type forms mentioned in the opening paragraph above. In the attempts to still further subdivide the group, scarcely two systematists are agreed as to the characters on which sub-classes are to be based. Thus De Bary divides bacteria according as they are endosporous or arthrosporous, and this, along with the planes in which division takes place, constitutes the chief basis on which sub-classes have rested. Other characters, such as presence or absence of flagella, appearances of bacteria when grouped together in masses, physiological and even pathogenic properties, have been utilised by different authors as means of classification. Our present knowledge of the essential morphology and relations of the group is as yet too limited for a really natural classification to be attempted. To prepare for the elaboration of the latter, Marshall Ward suggests that in every species there should be studied the habitat, best food supply, condition as to gaseous environment, range of growth, temperature, morphology, and life history, special properties and pathogenicity.

We must thus be content with a provisional and incomplete classification. We have said that the division into lower and higher bacteria is recognised by all, though, as in every other classification, there occur transitional forms. In subdividing the bacteria further, the forms they assume constitute at present the only practicable basis of classification. The lower bacteria thus naturally fall into the three groups mentioned, the cocci, bacilli, and spirilla, though the higher are more difficult to deal with. Subsidiary, though important, points in still further subdivision are the planes in which fission takes place and the presence or absence of spores. The recognition of actual species is often a matter of great difficulty. The points to be observed in this will be discussed later (p. 109).

I. The Lower Bacteria.[1]—These, as we have seen, are minute unicellular masses of protoplasm surrounded by an envelope, the total vital capacities of a species being represented in every cell. They present three distinct type forms, the coccus, the bacillus, and the spirillum, and endogenous sporulation may occur. They may also be motile.

1. *The Cocci.*—In this group the cells range in different species from .9-8 μ in diameter, but mostly measure 1-1.5 μ. Before division they may increase in size in all directions. The species are usually classified according to the method of division. If the cells divide only in one axis, and through the consistency of their envelopes remain attached, then a chain of cocci will be formed. A species in which this occurs is known as a *streptococcus*. If division takes place irregularly the resultant mass may be compared to a bunch of grapes, and the species is often called a *staphylococcus*. Division may take place in two axes at right angles to one another, in which case cocci adherent to each other in packets of four (called *tetrads*) or sixteen, may be found, the former number being the frequent unit. To all these forms the word *micrococcus* is often generally applied. The individuals in a growth of micrococci often show a tendency to remain united in twos. These are spoken of as *diplococci*, but this is not a distinctive character, as every coccus as a result of division becomes a diplococcus, though in some species the tendency to remain in pairs is well marked. The adhesion of cocci to one another depends on the character of the capsule. Often this has a well-marked outer limit (micrococcus tetragenus), sometimes it is of great extent, its diameter being many times that of the coccus (streptococcus mesenteriodes). It is especially among the streptococci and staphylococci that the phenomenon of the formation of arthrospores is said to occur. In none of the cocci have endogenous spores been certainly observed. The number of species of the streptococci and staphylococci probably exceeds 150. Besides those men-

[1] For the illustration of this and the succeeding systematic paragraphs, *vide* Fig. 1.

tioned there are cocci which divide in three axes perpendicular to one another. These are usually referred to as *sarcinæ*. If the cells are lying single they are round, but usually they are seen in cubes of eight with the sides which are in contact slightly flattened. Large numbers of such cubes may be lying together. The sarcinæ are, as a rule, rather larger than the other members of the group. Most of the cocci are non-motile, but two motile species possessing flagella have been described.

2. *Bacilli.*—These consist of long or short cylindrical cells, with rounded or sharply rectangular ends, usually not more than 1 μ broad, but varying very greatly in length. They may be motile or non-motile. Where flagella occur, these may be distributed all round the organism, or only at one or both of the poles (pseudomonas). Several species are provided with sharply-marked capsules (B. pneumoniæ). In many species endogenous sporulation occurs. The spores may be central or terminal, round, oval, or spindle-shaped.

Great confusion in nomenclature has arisen in this group in consequence of the different artificial meanings assigned to the essentially synonymous terms bacterium and bacillus. Migula, for instance, applies the former term to non-motile species, the latter to the motile. Hueppe, on the other hand, calls those in which endogenous sporulation does not occur, bacteria, and those where it does, bacilli. In the ordinary terminology of systematic bacteriology the word bacterium has been almost dropped, and is reserved, as we have done, as a general term for the whole group. It is usual to call all the rod-shaped varieties bacilli.

3. *Spirilla.*—These consist of cylindrical cells more or less spiral or wavy. Of such there are two main types. In one there is a long non-septate, usually slender, wavy, or spiral thread (*e.g.*, spirillum of relapsing fever, Fig. 1, No. 9). In other species the unit is a short curved rod (often referred to as of a "comma" shape). When two or more of the latter occur, as they often do, end to end with their curves alternating, then a wavy or spiral thread results. An example of this is the cholera microbe (Fig. 1, No. 10). This latter

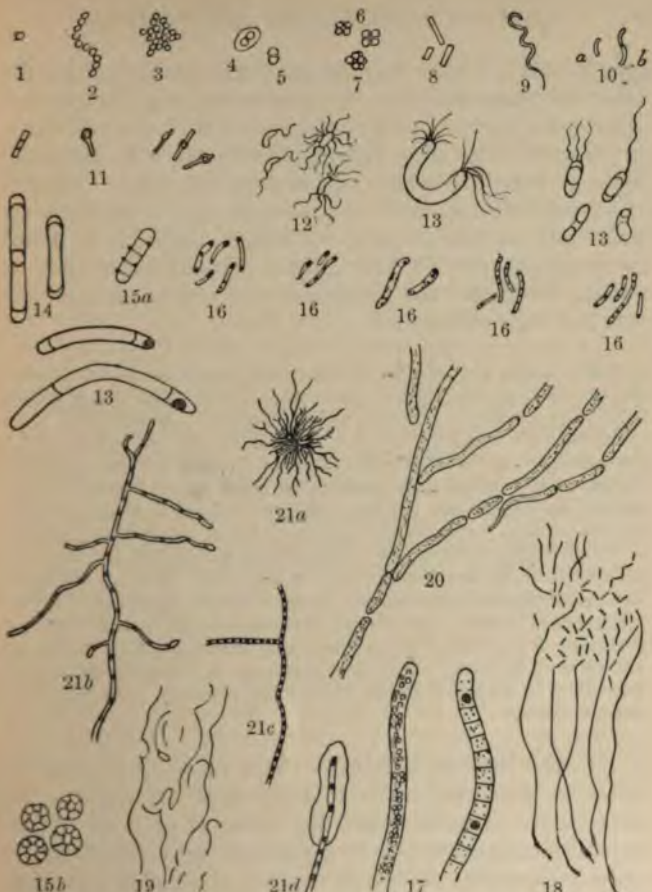

FIG. 1.—1. Coccus. 2. Streptococcus. 3. Staphylococcus. 4. Capsulated diplococcus. 5. "Biscuit"-shaped coccus. 6. Tetrads. 7. Sarcina form. 8. Types of bacilli (1-8 are diagrammatic). 9. Non-septate spirillum ×1000. 10. Ordinary spirillum—(*a*) comma-shaped element; (*b*) formation of spiral by comma-shaped elements ×1000. 11. Types of spore formation. 12. Flagellated bacteria. 13. Changes in bacteria produced by plasmolysis (after Fischer). 14. Bacilli with terminal protoplasm (Bütschli). 15. (*a*) Bacillus composed of five protoplasmic meshes; (*b*) protoplasmic network in micrococcus (Bütschli). 16. Bacteria containing metachromatic granules (Ernst, Neisser). 17. Beggiatoa alba. Both filaments contain sulphur granules—one is septate. 18. Thiothrix tenuis (Winogradski). 19. Leptothrix innominata (Miller). 20. Cladothrix dichotoma (Zopf). 21. Streptothrix actinomyces (Boström), (*a*) colony under low power; (*b*) filament showing true branching; (*c*) filament containing coccus-like bodies; (*d*) filament with club at end.

type is of much more frequent occurrence, and contains the more important species. Motility among the first group is often not associated, as far as is known, with the possession of flagella. The cells here apparently move by an undulating or screw-like contraction of the protoplasm. Most of the motile spirilla, however, possess flagella. Of the latter there may be one or two, or a bunch containing as many as twenty, at one or both poles. Division takes place as among the bacilli, and in some species endogenous sporulation has been observed.

Three terms are used in dividing this group, to which different authors have given different meanings. These terms are spirillum, spirochæta, vibrio. Migula makes "vibrio" synonymous with "microspira," which he applies to members of the group which possess only one or two polar flagella; "spirillum" he applies to similar species which have bunches of polar flagella, while "spirochæta" is reserved for the long unflagellated spiral cells. Hueppe applies the term "spirochæta" to forms without endospores, "vibrio" to those with endospores in which during sporulation the organism changes its form, and "spirillum" to the latter when no change of form takes place in sporulation. Flügge, another systematist, applies "spirochæta" and "spirillum" indiscriminately to any wavy or corkscrew form, and "vibrio" to forms where the undulations are not so well marked. It is thus necessary, in denominating such a bacterium by a specific name, to give the authority from whom the name is taken.

II. The Higher Bacteria.—These show advance on the lower in consisting of definite filaments branched or unbranched. In most cases the filaments at more or less regular intervals are cut by septa into short rod-shaped or curved elements. Such elements are more or less interdependent on one another, and special staining methods are often necessary to demonstrate the septa which demarcate the individuals of a filament. There is further often a definite membrane or sheath common to all the elements in a filament. Not only, however, is there this close organic relationship between the elements of the higher bacteria, but there is also interdependence of function; for example, one end of a filament is frequently concerned merely in

attaching the organism to some other object. The greatest advance, however, consists in the setting apart among most of the higher bacteria of the free terminations of the filaments for the production of new individuals. The protoplasm then undergoes special changes, whereby small rod-shaped forms (differing often in appearance from the elements of which the filament is composed) are produced. These are often called conidia ; they are often motile, and it is from them that new individuals are developed. There are various classes under which the species of the higher bacteria are grouped ; but our knowledge of them is still somewhat limited, as many of its members have not yet been artificially cultivated. The *beggiatoa* group consists of free swimming forms, motile by undulating contractions of their protoplasm. For the demonstration of the rod-like elements of the filaments special staining is necessary. The filaments have no special sheath, and the protoplasm contains sulphur granules. The method of reproduction is doubtful. The *thiothrix* group resembles the last in structure, and the protoplasm also contains sulphur granules ; but the filaments are attached at one end, and at the other form conidia. The *leptothrix* group resembles closely the thiothrix group, but the protoplasm does not contain sulphur granules. In the *cladothrix* group there is the appearance of branching, which, however, is of a false kind. What happens is that a terminal cell divides. It divides again, and pushes the product of its first division to one side. There are thus two terminal cells lying side by side, and as each goes on dividing, the appearance of branching is given. Here, again, there is conidium formation ; and while the parent organism is in some of its elements motile, the conidia move by means of flagella. The highest development is in the *streptothrix* group, to which belongs the streptothrix actinomyces, or the actinomyces bovis, an important pathogenic agent. Here the organism consists of a felted mass of non-septate filaments, in which true dichotomous branching occurs. Under certain circumstances threads grow out, and produce chains of coccus-

like bodies from which new individuals can be reproduced. Such bodies are often referred to as spores, but they have not the same staining reactions nor resisting powers of so high a degree as ordinary bacterial spores. Sometimes also the protoplasm of the filaments breaks up into bacillus-like elements, which may also have the capacity of originating new individuals. In the streptothrix actinomyces there may appear a club-shaped swelling of the membrane at the end of the filament, which has by some been looked on as a spore formation, but which is most probably a product of a degenerative change. The streptothrix group as a whole is a link between the bacteria on the one hand, and the lower fungi on the other. Like the latter, the streptothrix forms show the felted mass of non-septate branching filaments, which is usually called a mycelium. On the other hand, the breaking up of the protoplasm of the streptothrix into coccus- and bacillus-like forms, links it to the other bacteria.

General Biology of the Bacteria.

There are five prime factors which must be considered in the growth of bacteria, namely, food supply, moisture, relation to gaseous environment, temperature, and light.

Food Supply.—The great function performed by bacteria in nature is the breaking up into simpler constituents of the complicated organic substances which form the bodies of dead plants and animals, or which are excreted by the latter while they are yet alive. The natural food of bacteria is therefore of an extremely complex nature. Not only is it so to start with, but seeing that, to speak generally, many bacteria grow side by side, the food supply of any particular variety of the latter is, relatively to it, altered by the growth of the other varieties present. It is thus impossible to imitate the natural food environment of any species. The artificial media used in bacteriological work may therefore be poor substitutes for the natural supply. In certain cases, however, the conditions under which we

grow cultures may be better than they naturally are. For while one of two species of bacteria growing side by side may favour the growth of the other, it may also in certain cases hinder it, and, therefore, when the latter is grown alone it may grow better. Most bacteria seem to produce excretions which are unfavourable to their own vitality, for it is a frequent experience that, when a species is sown on a mass of artificial food medium, it does not in the great majority of cases go on growing till the food supply is exhausted, but soon ceases to grow. Effete products probably diffuse out into the medium and prevent growth. Evidence of such diffusion may be seen when the organism produces pigment, which frequently can be observed in a transparent medium far beyond the limit of the growth of the organism, *e.g.*, B. pyocyaneus growing on gelatine. In supplying artificial food for bacterial growth, the general principle ought to be to imitate as nearly as possible the natural surroundings, though it is found that there exists a considerable adaptability among organisms. With the pathogenic varieties it is usually found expedient to use media derived from the fluids of the animal body, and in cases where bacteria growing on plants are being studied, infusions of the plants on which they grow are frequently used. With some bacteria special substances are necessary to support life. Thus some species, in the protoplasm of which sulphur granules occur, require sulphuretted hydrogen to be present. In nature the latter is usually provided by the growth of other bacteria. While the result of the vital activity of bacteria is in most cases to break up complex organic bodies into simpler bodies, in certain cases a building-up process may take place. This occurs in the sulphur bacteria just mentioned, where the sulphur is oxidised into sulphates, and also in the nitrifying bacteria of the soil, referred to below (p. 29), which form nitrites and nitrates from ammonia, and in some cases from the free nitrogen of the air. When the food supply of a bacterium fails, it degenerates and dies. The proof of death lies in the fact

that when it is transferred to fresh and good food supply it does not multiply. It is during the process of degeneration that the involution forms already mentioned occur. If the bacterium spores, it may then survive the want of food for a very long time. It may here be stated that the reaction of the food medium is a matter of great importance. Most bacteria prefer a slightly alkaline medium, and some, *e.g.*, the cholera vibrio, will not grow in the presence of the smallest amount of free acid.

Moisture.—The presence of water is necessary for the continued growth of all bacteria. The amount of drying which bacteria in the vegetative stage will resist varies very much in different species. Thus the cholera spirillum is killed by two or three hours' drying, while the staphylococcus pyogenes aureus will survive ten days' drying, and the bacillus diphtheriæ still more. In the case of spores the periods are much longer. Anthrax spores will survive drying for several years, but here again moisture enables them to resist longer than when they are quite dry. When organisms have been subjected to such hostile influences, even though they survive, it by no means follows that they retain all their properties.

Relation to Gaseous Environment.—The relation of bacteria to the oxygen of the air is such an important factor in the life of bacteria that it enables a biological division to be made among them. Some bacteria will only live and grow when oxygen is present. To these the title of *obligatory aërobes* is given. Other bacteria will only grow when no oxygen is present. These are called *obligatory anærobes*. In still other bacteria the presence or absence of oxygen is a matter of indifference. This group might theoretically be divided into those which are preferably aërobes, but could be anærobes, and those which are preferably anærobes, but could be aërobes. As a matter of fact such differences are manifested to a slight degree, but all such organisms are usually grouped as *facultative anærobes*, *i.e.*, preferably aërobic but capable of existing without oxygen. Examples of obligatory aërobes are

B. proteus vulgaris, bacillus subtilis; of obligatory anærobes, B. tetani, B. œdematis maligni, B. anthracis symptomatici; while the great majority of pathogenic bacteria are facultative anærobes. With regard to anærobes, hydrogen and nitrogen are indifferent gases. Many anærobes, however, do not flourish well in an atmosphere of carbon dioxide. Very few experiments have been made to investigate the action on bacteria of gas under pressure. A great pressure of carbon dioxide is said to make the B. anthracis lose its power of sporing, but it seems to have no effect on its vitality nor on that of the B. typhosus. With the bacillus pyocyaneus, however, it is said to destroy life.

Temperature.—For every species of bacterium there is a temperature at which it grows best. This is called the "optimum temperature." There is also in each case a maximum temperature above which growth does not take place, and a minimum temperature below which growth does not take place. As a general rule the optimum temperature is about the temperature of the natural habitat of the organism. For organisms taking part in the ordinary processes of putrefaction the temperature of warm summer weather (20° to 24° C.) may be taken as the average optimum, while for organisms normally inhabiting animal tissues 35° to 39° C. is a fair average. The lowest limit of ordinary growth is from 12° to 14° C., and the upper is from 42° to 44° C. In exceptional cases growth may take place as low as 5° C., and as high as 70° C. It is to be noted that while growth does not take place below or above a certain limit it by no means follows that death takes place outside such limits. Organisms can stand being cooled below their minimum or heated beyond their maximum without being killed. Their vital activity is merely paralysed. Especially is this true of the effect of cold on bacteria. The results of different observers vary; but if we take as an example the cholera vibrio, while Koch found that the minimum temperature of growth was 16° C., a growth is said to have been cooled to −32° C. without being killed. With regard to the upper limit, few ordinary organisms in a

spore-free condition will survive a temperature of 57° C., if long enough applied. Many organisms lose some of their properties when grown at unnatural temperatures. Thus many pathogenic organisms lose their virulence if grown above their optimum temperature, and some chromogenic forms, most of which prefer rather low temperatures, lose their capacity of producing pigment, *e.g.*, spirillum rubrum. Some organisms which can grow at a temperature of from 60° to 70° C. have been isolated from dung, the intestinal tract, etc. These have been called *thermophilic* bacteria.

Effect of Light.—Of recent years much attention has been paid to this factor in the life of bacteria. Direct sunlight is found to have a very inimical effect. One observer found that an exposure of dry anthrax spores for one and a half hours to sunlight killed them. When they were moist, a much longer exposure was necessary. Typhoid bacilli were killed in about one and a half hours, and similar results have been obtained with many other organisms. In such experiments the thickness of the medium surrounding the growth is an important point. Death takes place more readily if the medium is scanty or if the organisms are suspended in water. Any fallacy which might arise from the effect of heat rays of the sun has been excluded, though light plus heat is more fatal than light alone. In direct sunlight it is chiefly the green, violet, and, it may be, the ultra-violet rays which are fatal. Diffuse daylight has also a bad effect upon bacteria, though it takes a very much longer exposure to do serious harm. A powerful electric light is as fatal as sunlight. Here, as with other factors, the results vary very much with the species under observation, and a distinction must be drawn between a mere cessation of growth and the condition of actual death.

Conditions affecting the Movements of Bacteria.—In some cases differences are observed in the behaviour of motile bacteria, contemporaneous with changes in their life history. Thus, in the case of bacillus subtilis, movement ceases when sporulation is about to take place. On the other

hand, in the bacillus of symptomatic anthrax, movement continues while sporulation is progressing. Under ordinary circumstances motile bacteria appear not to be constantly moving but occasionally to rest. In every case the movements become more active if the temperature be raised. Most interest, however, attaches to movements which, from the use of an unscientific terminology, are often described as if they were purposive, that is when the bacilli are attracted to certain substances and repelled by others. Schenk, for instance, observed that motile bacteria were attracted to a warm point in a way which did not occur when the bacteria were dead and therefore only subject to physical conditions. His method was to introduce the upturned point of a copper rod into a drop of fluid containing the bacteria and suspended from the lower surface of a cover-glass. On warming the outer end of the rod, heat waves, of course, were conducted up to the point and the bacteria swarmed round the latter. Most important observations have been made on the attraction and repulsion exercised on bacteria by chemical agents which have been denominated respectively *positive* and *negative chemiotaxis*. Pfeiffer investigated this subject in many lowly organisms, including bacterium termo and spirillum undula. The method was to fill with the agent a fine capillary tube, closed at one end, and, introducing it into a drop of fluid containing the bacteria under a cover-glass, to watch the effect through the microscope. Fallacies due to the passing of the fluid out of the tube otherwise than by diffusion, to temperature changes, and to vibration, seem to have been excluded, and control experiments were performed with dead bacteria. The general result was to indicate that motile bacteria may be either attracted or repelled by the fluid in the tube. The effect of a given fluid differs in different organisms, and a fluid chemiotactic for one organism may not act on another. Degree of concentration is important, but the nature of the fluid is more so. Of inorganic bodies salts of potassium are the most powerfully attractive bodies, and in comparing organic

bodies the important factor is the molecular constitution. These observations have been confirmed by Ali-Cohen, who found that while the vibrio of cholera and the typhoid bacillus were scarcely attracted by chloride of potassium, they were powerfully influenced by potato juice. Further, the filtered products of the growth of many bacteria have been found to have powerful chemiotactic properties. It is evident that all these observations have a most important bearing on the action of bacteria, though we do not yet know their true significance. Corresponding chemiotactic phenomena are shown also by certain animal cells, *e.g.*, leucocytes, to which reference is made below.

The Parts played by Bacteria in Nature.—As has been said, the great function of bacteria is to break up into more simple combinations the complex molecules of the organic substances which form the bodies of plants and animals, or which are excreted by them. In some cases we know some of the stages of degeneration, but in most cases we know only general principles and sometimes only results. In the case of milk, for instance, we know that lactic acid is produced from the lactose by the action of the bacillus acidi lactici and of other bacteria. From urea we know that ammonium carbonate is produced by the micrococcus ureæ. That the very complicated process of putrefaction is due to bacteria is absolutely proved, for any organic substance can be preserved indefinitely from ordinary putrefaction by the adoption of some method of killing all bacteria present in it, as will be afterwards described. This statement, however, does not exclude the fact that molecular changes take place spontaneously in the passing of the organic body from life to death. Many processes not usually referred to as putrefactive are also bacterial in their origin. The souring of milk, already referred to, the becoming rancid of butter, the ripening of cream and of cheese, are all due to bacteria.

A certain comparatively small number of bacteria have been proved to be the causal agents in some disease

processes occurring in man, animals, and plants. This means that the fluids and tissues of living bodies are, under certain circumstances, a suitable pabulum for the bacteria involved. The effects of the action of these bacteria are analogous to those taking place in the action of the same or other bacteria on dead animal or vegetable matter. The complex organic molecules are broken up into simpler products. We shall study these processes more in detail later. Meantime we may note that the disease-producing effects of bacteria form the basis of another biological division of the group. Some bacteria are harmless to animals and plants, and apparently under no circumstances give rise to disease in either. These are known as saprophytes. They are normally employed in breaking up dead animal and vegetable matter. Others normally live on or in the bodies of plants and animals and produce disease. These are known as parasitic bacteria. Sometimes an attempt is made to draw a hard and fast line between the *saprophytes* and the *parasites*, and obligatory saprophytes or parasites are spoken of. This is an erroneous distinction. Some bacteria which are normally saprophytes can be made to produce pathogenic effects (bacillus œdematis maligni), and it is consistent with our knowledge that the best-known parasites may have been derived from saprophytes. On the other hand, the fact that most bacteria associated with disease processes, and proved to be the cause of the latter, can be grown in artificial media, shows that for a time at least such parasites can be saprophytic. As to how far such a saprophytic existence of disease-producing bacteria occurs in nature, we are in many instances still ignorant.

The Methods of Bacterial Action.—The processes which bodies being split up by bacteria undergo depend, first, on the chemical nature of the bodies involved and, secondly, on the varieties of the bacteria which are acting. The destruction of albuminous bodies which is mostly involved in the wide and varied process of putrefaction can be undertaken by whole groups of different varieties of bacteria. The

action of the latter on such substances is analogous to what takes place when albumins are subjected to ordinary gastric and intestinal digestion. In these circumstances, therefore, the production of albumoses, peptones, etc., similar to those of ordinary digestion, can be recognised in putrefying solutions, though the process of destruction always goes further, and still simpler substances are the ultimate results. The process is an exceedingly complicated one when it takes place in nature, and different bacteria are probably concerned in the different stages. Many other bacteria, *e.g.*, some pathogenic forms, though not concerned in ordinary putrefactive processes, have a similar digestive capacity. When carbohydrates are being split up, then various alcohols, ethers, and acids are produced. During bacterial growth there is not unfrequently the abundant production of such gases as sulphuretted hydrogen, carbon dioxide, methane, etc. For an exact knowledge of the destructive capacities of any particular bacterium there must be an accurate chemical examination of its effects when it has been grown in artificial media the nature of which is known. The precise substances it is capable of forming can thus be found out. Many substances, however, are produced by bacteria, of the exact nature of which we are still ignorant, for example, the toxic bodies which play such an important part in the action of many pathogenic species.

Many of the actions of bacteria depend on the production by them of *ferments* of a very varied nature and complicated action. Thus the digestive action on albumins depends on the production of a peptic ferment analogous to that produced in the animal stomach. Ferments which invert sugar, which split sugars up into alcohols or acids, which coagulate casein, which split up urea into ammonium carbonate, have all been isolated from different bacteria.

Such ferments may be diffused into the surrounding fluid, or be retained in the cells where they are made. Sometimes the breaking down of the organic matter appears to take place within, or in the immediate proximity of, the

bacteria, sometimes wherever the soluble ferments reach the organic substances. And in certain cases the ferments diffused out into the surrounding fluid probably break down the latter to some extent, and prepare it for a further, probably intracellular, disintegration. Thus in certain putrefactions of fibrin, if the process be allowed to go on naturally, the fibrin dissolves and ultimately great gaseous evolution of carbon dioxide and ammonia takes place, but if the bacteria, shortly after the process has begun, are killed or paralysed by chloroform, then only a peptonisation of the fibrin occurs, without the further splitting up and gaseous production being observed. That a purely intracellular digestion may take place is illustrated by what has been shown to occur in the case of the micrococcus ureæ, which from urea forms ammonium carbonate by adding water to the urea molecule. Here, if after the action has commenced, the bacteria are filtered off, no further production of ammonium carbonate takes place, which shows that no ferment has been dissolved out into the urine. If now the bodies of the bacteria be extracted with absolute alcohol or ether, which of course destroy their vitality, a substance is obtained of the nature of a ferment, which, when added to sterile urine, rapidly causes the production of ammonium carbonate. This substance has evidently been contained within the bacterial cells.

As has been said, some bacteria seem to be capable of building up out of simple chemical compounds bodies which are more complex. This function is best illustrated in a group of bacteria which probably play a most important economic function in fertilising the soil by converting ammonia compounds into nitrites and nitrates, and thus making the nitrogen more available for plant nutrition. These so-called nitrifying organisms have been investigated by Professor and Mrs. Frankland, by Professor Warington, and by Winogradski. Their isolation presented great difficulties, none of the ordinary methods being available, as the organisms sought were quickly overgrown by the ordinary bacteria of the soil. Winogradski, however, succeeded in getting fairly pure cultures by taking advantage of the fact that they were capable of growing in the entire absence of organic matter, to exclude which he took most elaborate precautions. The media used contained potassium phosphate, sulphate of magnesium, sulphate of ammonium,

basic carbonate of magnesium, and water. An inorganic gelatinous substance was sometimes added, namely, hydrate of silica. On such a medium ordinary bacteria could not develop to any extent. The nitrifying organisms flourished, and there was evidence of abundant oxidation of ammonia and the formation of nitrites, and to a less extent of nitrates. Not only so, but these organisms could derive their carbon from the carbonates present. There is evidence that the nitrifying organisms consist of two groups, one of which forms nitrites from ammonia compounds, the other forming nitrates from these nitrites. It is probable that other organisms exist which are capable of forming compounds by taking up the free nitrogen of the air. On the roots of all leguminous plants small nodules, usually called tubercles, are found. These are not developed if the plant is growing in soil free from bacteria, and plants thus grown are not so vigorous as those which grow in ordinary soil. Further, in the interior of these tubercles bacteria-like bodies are observed. There is a good deal of evidence that these are either bacteria or allied organisms, that they take up free nitrogen from the air, and make it available for the nutrition of the plant. If this be the case, a reason is found for the idea long held by agriculturists that the growth of a crop of beans or peas fertilises the soil and improves subsequent crops.

The Occurrence of Variability among Bacteria.—The question of the division of the group of bacteria into definite species has given rise to much discussion among vegetable and animal morphologists.

In 1872 Cohn stated the opinion that bacteria showed as distinct species as the other lower plants and animals. He recognised the great divisions into which bacteria naturally fall when the forms under which they appear are considered, but he carefully guarded himself against the error that mere considerations of form are sufficient for a proper natural classification of such a group. In such a classification the history of the whole life cycle of an organism, and especially the course of its development, must be taken into account. Variations in form occurring in particular cases have, however, been made the basis for criticism of the statement that the large numbers of bacteria which have been identified are really to be looked upon as distinct species. The extreme case for the existence of variability was put by Nägeli, who held that "the same species in the course of generations might present different morphological and physiological forms which might give rise at one time to the souring of milk, at another to butyric acid fermentation, at another to the putrefaction of albuminous matter, at another to diphtheria, at another to typhoid, at another to cholera." Such an extreme view was advanced before the elaboration by Koch

of methods by which growths of a single kind of bacteria without admixture of any other variety can be obtained. Undoubtedly many of the earlier observations were made on mixtures of different organisms. Thus the upholders of the occurrence of great variability founded their view very largely on observations of a group of organisms closely allied to the bacteria which, from a peculiar pigment called "purpurin" in their protoplasm, have been called the purpurin bacteria (German, Purpurbakterien). From a more recent study of the group by Winogradski, however, these seem to be a mixture of many different species, each of which maintains during multiplication its characteristic form. Practically no one at the present day holds that an organism can appear now as a bacillus, now as a coccus, now as a spirillum. Nor is such a view in any way supported by the occurrence in isolated cases among the higher bacteria of coccus-like and bacillus-like segmentation, such as we have seen to take place in the streptothrix group.

With regard to the bacteria as a whole we may say that each variety tends to conform to the definite type of structure and function which is peculiar to it. On the other hand, slight variations from such type can occur in each. The size may vary a little with the medium in which the organism is growing, and under certain similar conditions the adhesion of microbes to each other may also vary. Thus cocci, which are ordinarily seen in short chains, may grow in long chains. The capacity to form spores may be altered, and such properties as the elaboration of certain ferments or of certain pigments may be impaired. Also the characters of the growths on various media may undergo variations. As has been remarked, variation as observed consists largely in a tendency in a bacterium to lose properties ordinarily possessed. Practically no case of a bacterium acquiring new properties has been observed, and all attempts to transform one bacterium into an apparently closely allied variety (such as the B. coli into the B. typhosus) have failed. This of course does not preclude the possibility of one species having been originally derived from another or both having descended from a common ancestor, but we can say that only variations of an unimportant order have been observed to take place, and here it must be remembered that in many cases we can often have forty-eight or more

generations under observation within twenty-four hours. If we accept De Bary's definition of a species, we can have little difficulty in saying that such exist among the bacteria. The definition is: "By the term species we mean the sum total of the separate individuals and generations which, during the term afforded for observations, exhibit the same periodically repeated course of development within certain empirically determined limits of variation."

The Death of Bacteria.—The death of bacteria is usually judged of by the fact that, when they are transferred to a fresh quantity of an artificial medium in which they previously grew, no growth takes place. Under the microscope the counterpart of this of course would be the cessation of division when surrounded by such a medium. All bacteria can be killed by heat, drying, starvation, and chemical agents, as we have seen. Great attention has been paid to the latter, which are usually *antiseptics*, though *germicides* would be a more proper term to apply. The action of such agents depends on the variety of bacterium to be killed, on its state of nutrition, whether it is in a vegetative or a spored condition, on the temperature at which the agent acts, on the medium in which it acts, and on the nature of the chemical agent itself. Among inorganic bodies the salts of the metals with high atomic weights act more potently than those with lower, and the most powerful antiseptic bodies are probably the perchloride and periodide of mercury. The reaction of the agent is a point of great importance; as a general rule, the more powerful an acid is, the greater is its capacity as a germicide. The importance of oxidising and reducing agents as germicides has probably been overestimated. Among organic bodies the members of the aromatic series are all more or less potent—the favourite member for practical use being carbolic acid. In comparing the action of antiseptic agents the all-important point is their relative molecular constitution. From the number of conditions we have enumerated, which must be considered in estimating antisepticity, it is evidently impossible to make definite statements as to the value of

particular agents unless all the conditions are stated. As a general rule, however, the two solutions most commonly used, which will kill the greatest variety of bacteria in the shortest time, are a 1 in 20 solution of carbolic acid and a 1 in 1000 solution of perchloride of mercury.

CHAPTER II.

METHODS OF CULTIVATION OF BACTERIA.

Introductory.—In order to study the characters of any species of bacterium it is necessary to have it growing apart from every other species. In the great majority of cases where bacteria occur in nature, this condition is not fulfilled. In the general processes of putrefaction many different species occur all mingled with each other. Only in the blood and tissues in some diseases do particular species occur singly and alone. We usually have, therefore, to remove a bacterium from its natural surroundings and grow it on an artificial food medium. When we have succeeded in separating it, and have got it to grow on a medium which suits it, we are said to have obtained a *pure culture*. These pure cultures are absolutely necessary for the proper study of bacteria; for, when many individuals of a species are growing together, the mass formed by their aggregation frequently presents characteristic appearances which constitute specific differences. The recognition of different species of bacteria depends, in fact, far more on the characters presented by pure cultures and their behaviour in different food media, than on microscopic examination. The latter in most cases only enables us to refer a given bacterium to its class. For the greater number of specific characters we rely on the observation of pure cultures. Again, in inquiring as to the possible possession of pathogenic properties by a bacterium, the obtaining of pure

cultures is absolutely essential. If two or more different organisms be present together, we cannot say that any one of them is the cause of the disease in question.

To obtain pure cultures, then, is the first requisite of bacteriological research. Now, as bacteria are practically omnipresent, we must first of all have means of destroying all extraneous organisms which may be present in the food media to be subsequently used for growing the bacteria we wish to study, in the vessels in which the food media are contained, and on all instruments which are to come in contact with our cultures. The technique of this destructive process is called sterilisation. We must therefore study the *methods of sterilisation.* The growth of bacteria in other than their natural surroundings involves further the *preparation of sterile artificial food media*, and when we have such media prepared we have still to look at the technique of the *separation of micro-organisms from mixtures of these, and the maintaining of pure cultures when these have been obtained.* We shall here find that different methods are necessary according as we are dealing with *aërobes* or *anærobes.* Each of these methods will be considered in turn.

The Methods of Sterilisation.

To exclude extraneous organisms, all food materials, glass vessels containing them, wires used in transferring bacteria from one culture medium to another, instruments used in making autopsies, etc., must be sterilised. These objects being so different, various methods are necessary. The foods comprise meat infusions, jellies, potatoes, etc., and a method suitable for their sterilisation evidently may not be suitable for the sterilisation of, say, a glass flask. Bacteria may be killed by various methods. Many chemicals will kill them, but the difficulty of subsequently removing such chemicals, so that they may not interfere with the growth of the microbes we wish to cultivate, makes their use inapplicable. We therefore in practice take advantage of the principle that all bacteria are destroyed by heat.

The temperature necessary varies with different bacteria, and the vehicle of heat is also of great importance. The two vehicles employed are hot air and hot water or steam. The former is usually referred to as "dry heat," the latter as "moist heat." As showing the different effects of the two vehicles, Koch found, for instance, that the spores of *bacillus anthracis*, which were killed by moist heat at 100° C., in one hour, required three hours' dry heat at 140° C. to effect death. Both forms of heat may be applied at different temperatures—in the case of moist heat above 100° C., a pressure higher than that of the atmosphere must of course be present.

A. *Sterilisation by Dry Heat.*

(1) **Red Heat or Dull Red Heat.**—Red heat is used for the sterilisation of the platinum needles which, it will be found, are so constantly in use. A dull heat is used for cauteries, the points of forceps, and may be used for the incidental sterilisation of small glass objects (cover-slips, slides, occasionally when necessary even test-tubes), care of course being taken not to melt the glass. The heat is obtained by an ordinary Bunsen burner.

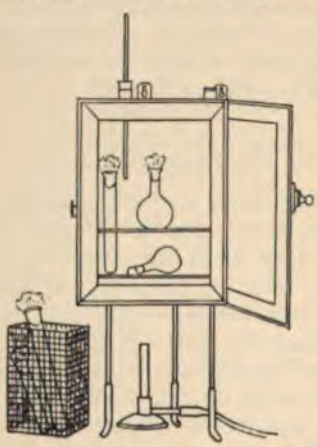

FIG. 2.—Hot-air steriliser.

(2) **Sterilisation by Dry Heat in a Hot-Air Chamber.**—The chamber (Fig. 2) consists of an outer and inner case of sheet iron. In the bottom of the outer there is a large hole. A Bunsen is lit beneath this, and thus plays on the bottom of the inner case, round all of the sides of which the hot air rises and escapes through holes in the top of the

outer case. A thermometer passes down into the interior of the chamber, half-way up which its bulb should be situated. It is found as a matter of experience, that an exposure in such a chamber for one hour to a temperature of 170° C., is sufficient to kill all the organisms which usually pollute articles in a bacteriological laboratory, though circumstances might arise where this would be insufficient. This means of sterilisation is used for the glass flasks, test-tubes, plates, Petri's dishes, the use of which will be described. Such apparatus are thus obtained sterile and dry. It is advisable to put glass vessels into the chamber before heating it, and to allow them to stand in it after sterilisation till the temperature falls. Sudden heating or cooling is apt to cause glass to crack. The method is unsuitable for food media. Solid media would be scorched by such a temperature, and fluid would not reach it at the ordinary pressure.

B. *Sterilisation by Moist Heat.*

(1) **By Boiling.**—The boiling of a liquid for five minutes is sufficient to kill ordinary germs if no spores be present, and this method is useful for sterilising distilled or tap water which may be required in various manipulations. It is best to sterilise knives and instruments used in autopsies by boiling in water, as dry heat frequently spoils the temper of the steel. Twenty minutes' boiling will here be sufficient. The boiling of any fluid at 100° C. for one and a half hours will ensure sterilisation under almost any circumstances.

(2) **By Steam at 100° C.**—This is by far the most useful means of sterilisation. It may be accomplished in an ordinary potato steamer placed on a kitchen pot. The apparatus ordinarily used is "Koch's steam steriliser" (Fig. 3). This consists of a tall metal cylinder on legs, provided with a lid, and covered externally by some bad conductor of heat. A perforated tin diaphragm is fitted in the interior at a little distance above the bottom, and there is a tap at the bottom by which water may be supplied or withdrawn. If

water to the depth of 3 inches be placed in the interior and heat applied, it will quickly boil, and the steam streaming up will surround any flask or other object standing on the diaphragm. It is convenient to have the cylinder tall enough to hold, standing in its neck, a litre flask with a funnel 7 inches in diameter. With such a "Koch" in the laboratory a hot-water filter is not needed. As has been said, one and a half hour's steaming will practically sterilise any medium, but as some of our most important media contain gelatine, such an exposure is not practicable, as with long boiling, gelatine tends to lose its physical property of solidification. The method adopted in this case is to steam for a quarter of an hour on each of three succeeding days. This is a modification of what is known as "Tyndall's intermittent sterilisation." The fundamental principle of this method is that all bacteria in a non-spored form are killed by the temperature of boiling water, while if in a spored form they may not be thus killed. Thus by the sterilisation on the first day all the non-spored forms are destroyed—the spores remaining alive. During the twenty-four hours which intervene before the next heating, these spores, being in a favourable medium, are likely to assume the non-spored form. The next heating kills these. In case any may still not have changed their spored form, the process is repeated on a third day. Experience shows that usually the medium can now be kept indefinitely in a sterile condition. Steam at 100° C. is therefore available for the sterilisation of all ordinary media. In using the Koch's steriliser, especially when a large bulk of medium is to be sterilised, it is best to put the media in while the apparatus is cold, in order to make certain that the whole of the food mass reaches the temperature of 100° C. The period of exposure

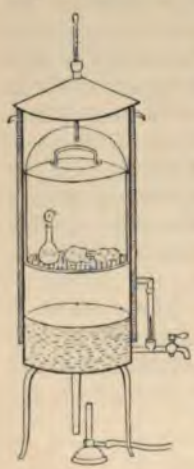

FIG. 3.—Koch's steam steriliser.

is reckoned from the time the ebullition commences in the water in the steriliser. At any rate allowance must always be made for the time required to raise the medium to the temperature in which it is placed.

If we wish to use such a substance as blood serum as a medium, the albumin would be coagulated by a temperature of 100° C. Therefore other means have to be adopted in this case.

(3) **Sterilisation by Steam at High Pressure.**—This is the most rapid and effective means of sterilisation. It is effected in an autoclave (Fig. 4). This is a copper cylinder on legs, the top of which is fastened down with screws and nuts and is furnished with a safety valve, pressure-gauge, and a hole for thermometer. As in the Koch's steriliser, the contents are supported on a perforated diaphragm. The source of heat is a large Bunsen beneath. The temperature employed is usually 115° C. or 120° C., To boil at 115° C., water requires a pressure of about 23 lbs. to the square inch (*i.e.* 8 lbs. plus the 15 lbs. of ordinary atmospheric pressure). To boil at 120° C., a pressure of about 30 lbs. (*i.e.* 15 lbs. plus the usual pressure) is necessary. When in such an apparatus the desired temperature has been reached, the latter is maintained by adjusting the safety valve so as to blow off. One exposure of media to such temperatures for a quarter of an hour is sufficient to kill all organisms or spores. Here, again, care must be taken when gelatine is to be sterilised. It must not be exposed to a temperature above 105°, and must be sterilised by the intermittent method. Certain precautions are necessary in using the autoclave. In all cases it is necessary to allow the apparatus to cool well below 100° C., before opening it or allowing steam to blow off, otherwise

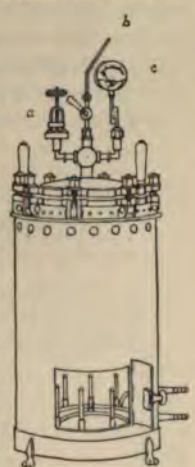

FIG. 4.—Autoclave. *a.* Safety valve. *b.* Blow-off pipe. *c.* Gauge.

there will be a sudden development of steam when the pressure is removed, and fluid media will be blown out of the flasks. Sometimes the instrument is not fitted with a thermometer. In this case care must be taken to expel all the air initially present, otherwise a mixture of air and steam being present, the pressure read off the gauge cannot be accepted as an indication of the temperature. Further, care must be taken to ensure the presence of a residuum of water when steam is fully up, otherwise the steam is superheated, and the pressure on the gauge again does not indicate the temperature correctly.

(4) **Sterilisation at Low Temperatures.**—Most organisms in a non-spored form are killed by a prolonged exposure to a temperature of 57° C. This fact has been taken advantage of for the sterilisation of blood serum, which will coagulate if exposed to a temperature above that point. Such a medium is sterilised on Tyndall's principle by exposing it for an hour at 57° C. for eight consecutive days, it being allowed to cool in the interval to the room temperature. The apparatus used (Fig. 5) is a small hot-water jacket heated by a Bunsen placed beneath it, the temperature being controlled by a gas regulator. To ensure that the temperature all round shall be the same, the lid also is hollow and filled with water, and there is a special gas burner at the side to heat it.

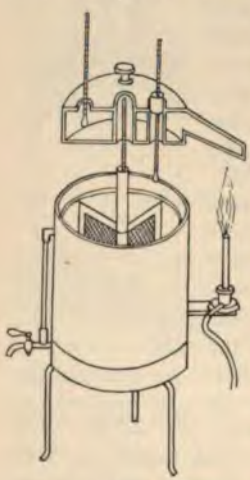

FIG. 5.—Steriliser for blood serum.

THE PREPARATION OF CULTURE MEDIA.

The general principle to be observed in the artificial culture of bacteria is that the medium used should approxi-

mate as closely as possible to that on which the bacterium grows naturally. In growing pathogenic bacteria, the medium therefore should resemble the juices of the body. The serum of the blood satisfies this condition and is often used, but its application is limited by the difficulties in its preparation and preservation. Other media have been found which can support the life of all the pathogenic bacteria isolated. These consist of proteids or carbohydrates in a fluid, semi-solid or solid form, in a transparent or opaque condition. The advantage of having a variety of media lies in the fact that growth characters on particular media, non-growth on some and growth on others, etc., constitute specific differences which are valuable in the identification of bacteria. The most commonly used media have as their basis a watery extract of meat. Most bacteria in growing in such an extract cause only a grey turbidity. A great advance resulted when Koch, by adding to it gelatine, provided a transparent solid medium in which growth characteristics of particular bacteria become evident. Many organisms, however, grow best at a temperature at which this nutrient gelatine melts, and therefore another gelatinous substance called agar, which does not melt below 98° C., was substituted. Bouillon made from meat extract, gelatine, and agar media, and the modifications of these, constitute the chief materials in which bacteria are grown.

Preparation of Meat Extract.

Ox flesh or horse flesh (preferably the latter for most purposes on account of its cheapness and freedom from fat) is taken. It ought to be from an animal recently killed, and should therefore be markedly acid to litmus paper. It must be freed from fat, and finely minced. For each pound of mince add 1000 c.c. distilled water, and mix thoroughly in a shallow dish. Skim off any fat present, removing the last traces by stroking the surface of the fluid with pieces of filter paper. Set aside in a cool place for twenty-four hours. Place a clean linen cloth over the mouth

of a large filter funnel, and strain the fluid through it into a flask. Pour the minced meat into the cloth, and gathering up the edges of the cloth in the left hand, squeeze out the juice still held back in the contained meat. Finish this expression by putting the cloth and its contents into a meat press (Fig. 6), similar to that used by pharmacists in preparing extracts; thus squeeze out the last drops. The resulting sanguineous fluid contains the soluble albumins of the meat, the soluble salts, extractives, and colouring matter, chiefly hæmoglobin. It is now boiled thoroughly for two hours, by which process the albumins coagulable by heat are coagulated. Strain now through a clean cloth, boil for another half-hour, and filter through white Swedish filter paper (best C. Schleicher u. Schull, No. 595). Make up to 1000 c.c. with distilled water. The resulting fluid ought to be quite transparent, of a yellowish colour without any red tint. If there is any redness, the fluid must be reboiled and filtered till this colour disappears, otherwise in the later stages it will become opalescent. A large quantity of the extract may be made at a time, and what is not immediately required is put into a large flask, the neck plugged with cotton wool, and the whole sterilised by methods B (2) or (3). This extract contains very little albuminous matter, and consists chiefly of the soluble salts of the muscle, certain extractives, and altered colouring matters, along with any slight traces of soluble proteid not coagulated by heat. It is of acid reaction. We have now to see how, by the addition of proteid and other matter, it may be transformed into proper culture media.

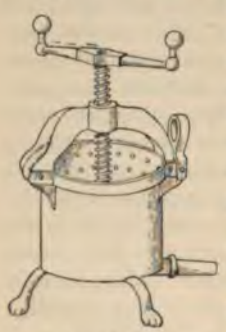

FIG. 6.—Meat press.

1. **Bouillon Media.**—These consist of meat extract with the addition of certain substances to render them suitable for the growth of bacteria.

1 (*a*). **Peptone Broth or Bouillon.**—Add to the meat

extract .5 per cent sodium chloride and 1 per cent peptone albumin. Boil till both are quite dissolved, and neutralise with a saturated solution of sodium carbonate. Add the latter drop by drop, shaking thoroughly between each drop and testing the reaction by means of litmus paper. Go on till the reaction is slightly but distinctly alkaline. This neutralisation must be practised with great care, as under certain circumstances, depending on the relative proportions of the different phosphates of sodium and potassium, what is known as the amphoteric reaction is obtained, *i.e.* red litmus is turned blue, and blue red, by the same solution. The sodium carbonate must therefore be added till red litmus is turned slightly but distinctly blue, and blue litmus is not at all tinted red. After alkalinisation, allow the fluid to become cold, filter through Swedish filter paper into flasks, make up to original volume with distilled water, plug the flasks with cotton wool, and sterilise by methods B (2) or (3), pp. 37, 39.

In this medium the place of the original albumins of the meat is taken by peptone, a soluble proteid not coagulated by heat. Here it may be remarked that the commercial peptone albumin is not pure peptone, but a mixture of albumoses (see footnote, Chap. V.) with a variable amount of pure peptone. The addition of the sodium chloride is necessitated by the fact that alkalinisation precipitates some of the phosphates and carbonates present. Experience has shown that sodium chloride can quite well be substituted. The reason for the alkalinisation is that it is found that most bacteria grow best on a slightly alkaline medium. Some, *e.g.* the cholera vibrio, will not grow at all on even a slightly acid medium.

1 (*b*). **Glucose Broth.**—To the other constituents of 1 (*a*) there is added 1 or 2 per cent of grape sugar. The steps in the preparation are the same. Glucose being a reducing agent, no free oxygen can exist in a medium containing it, and therefore glucose broth is used as a culture fluid for anærobic organisms.

1 (*c*). **Glycerine Broth.**—The initial steps are the same

as in 1 (*a*), but *after filtration* 6 to 8 per cent of glycerine (sp. grav. 1.25) is added. This medium is especially used for growing the tubercle bacillus when the soluble products of the growth of the latter are required.

2. **Gelatine Media.**—These are simply the above broths, with gelatine added as a solidifying body.

2 (*a*). **Peptone Gelatine.**—Take of meat extract say 1000 c.c., add 5 grams sodium chloride, 10 grams peptone, and from 100 to 150 grams gelatine (the "gold label" gelatine of Coignet et Cie., Paris, is the best). The gelatine is cut into small pieces, and added with the other constituents to the extract. They are then thoroughly melted on a sand bath, or in the "Koch," and the fluid neutralised as in 1 (*a*), and filtered through filter paper. As the medium must not be allowed to solidify during the process, it must be kept warm. This is effected by putting the flask and funnel into a tall Koch's steriliser, in which case the funnel must be supported on a tripod, as there is great danger of the neck of the flask breaking if it has to support the funnel and its contents. The filtration may also be carried out in a hot-water funnel (Fig. 7). This consists of an outer tin funnel, the neck of which is fitted with a perforated cork, through which is placed the stem of an inner glass funnel, the diameter of whose mouth is less than that of the outer funnel. The interspace between the two funnels is filled with water, which is kept hot by a Bunsen under a side arm let into the outer funnel. Whichever instrument be used, before filtering shake up the melted medium, as it is apt while melting to have settled into layers of different density. Sometimes what first comes through is turbid. If so, replace it in the unfiltered part: often the subsequent filtrate in such circumstances is quite clear. A litre flask

FIG. 7.—Hot-water funnel.

of the finished product ought to be quite transparent. If instead it is partially opaque, add the white of an egg and boil thoroughly over the sand bath. The consequent coagulation of the albumin carries down the opalescent material, and on making up with distilled water to the original quantity and refiltering, it will be found to be clear. The flask containing it is then plugged with cotton wool and sterilised, best by method B (2), p. 37. If the autoclave be used the temperature employed must not be above 105° C., and exposure not more than a quarter of an hour. Too much boiling, or boiling at too high a temperature, as has been said, causes a gelatine medium to lose its property of solidification. This transparent solid gelatine medium is that chiefly employed for the culture of aërobic bacteria at ordinary temperatures. The exact percentage of gelatine used in its preparation depends on the temperature at which growth is to take place. Its firmness is its most valuable characteristic, and to maintain this in summer weather, 15 parts per 100 are necessary. A limit is placed on higher percentages by the fact that, if the gelatine be too stiff, it will split on the perforation of its substance by the platinum needle used in inoculating it with a bacterial growth; 15 per cent gelatine melts at about 24° C.

2 (*b*). **Glucose Gelatine.**—The constituents are the same as 2 (*a*), with the addition of 1 to 2 per cent of grape sugar. The method of preparation is identical. This medium is used for growing anærobic organisms at the ordinary temperatures.

3. **Agar Media (French, "gélose").**—The disadvantage of gelatine is that at the blood temperature (38° C.), at which most pathogenic organisms grow best, it is liquid. To get a medium which shall be solid at this temperature, agar is used as the stiffening agent instead of gelatine. Unlike the latter, which is a proteid, agar is a carbohydrate. It is derived from the stems of various sea-weeds growing in the Chinese seas, popularly classed together as "Ceylon Moss." The best for bacteriological purposes is that consisting of the thin dried stem of the sea-weed itself.

3 (*a*). **"Ordinary" Agar.** — Prepare peptone bouillon, medium 1 (*a*), up to the stage of sterilisation. For every 100 c.c. take 1.5 grams agar. Cut it up into very fine fragments (in fact till it is as nearly as possible dust), add to the bouillon and allow to stand all night. Then boil in a water bath for five hours, till the agar is thoroughly melted. Test with litmus to see that reaction is still slightly alkaline, and filter. Filtration here is a very slow process and must be carried out in a tall Koch's steriliser. In doing this, it is well to put a glass plate over the filter funnel to prevent condensation water from dropping off the roof of the steriliser into the medium. If a slight degree of turbidity may be tolerated, it is sufficient to filter through a felt bag or jelly strainer. Plug the flask containing the filtrate, and sterilise either in autoclave for fifteen minutes or in Koch's steriliser for one and a half hours. Agar melts just below 100° C., and on cooling solidifies about 39° C.

3 (*b*). **Glycerine Agar.**—To 3 (*a*) after filtration add 6 to 8 per cent of glycerine and sterilise as above. This is used especially for growing the tubercle bacillus.

3 (*c*). **Glucose Agar.**—Prepare as in 3 (*a*), but add 1 to 2 per cent of grape sugar along with agar. This medium is used for the culture of anærobic organisms at temperatures above the melting point of gelatine. It is also a superior culture medium for some aërobes, *e.g.* the B. diphtheriæ.

These bouillon, gelatine, and agar preparations constitute the most frequently used media. Growths on bouillon do not usually show any characteristic appearances which facilitate classification, but such a medium is of great use in investigating the soluble toxic products of bacteria. The most characteristic developments of organisms take place on the gelatine media. These have, however, the disadvantage of not being available when growth is to take place at any temperature above 24° C. For higher temperatures agar must be employed. Agar is, however, never so transparent. Though quite clear when fluid, on solidifying, it always becomes slightly opaque. Further, growths upon it are never so characteristic as those on

gelatine. It is, for instance, never liquefied, whereas some organisms, by their growth, liquefy gelatine and others do not, a fact of prime importance.

Sometimes to the above media are added colouring matters, changes in which may give information as to the nature of the action of bacteria. Thus the production of acids can be detected by adding a few drops of a watery solution of litmus (French, tournesol) to the ordinary bouillon or gelatine. In the case of the B. diphtheriæ ordinary bouillon may be used. Sanarelli used a 2 per cent lactose gelatine tinted blue with a little litmus, to distinguish the acid-producing bacillus coli communis, from the typhoid bacillus.

Agar smeared with Blood.—This method was introduced by Pfeiffer for growing the influenza bacillus, and it has been used for the organisms which are not easily grown on the ordinary media, *e.g.* the gonococcus and the pneumococcus. Human blood or the blood of animals may be used. "Sloped tubes" (*vide* p. 54) of agar are employed (glycerine agar is not so suitable). Purify a finger first with 1-1000 corrosive sublimate, dry, and then wash with absolute alcohol to remove the sublimate. Allow the alcohol to evaporate. Prick with a needle sterilised by heat, and, catching a drop of blood in the loop of a sterile platinum wire (*vide* p. 55), smear it on the surface of the agar. The excess of the blood runs down and leaves a film on the surface. Cover the tubes with india-rubber caps, and incubate them for one to two days at 38° C. before use, to make certain that they are sterile.

Blood Serum.

Koch introduced this medium, and it is prepared as follows: Plug the mouth of a tall cylindrical glass vessel (say a 1000 c.c. measure) with cotton wool, and sterilise by steaming it in a Koch's steriliser for one and a half hours. Take it to the place where a horse, ox, or sheep is to be killed. When the artery or vein of the animal is opened, allow the

first blood which flows, and which may be contaminated from the hair, etc., to escape; fill the vessel with the blood subsequently shed. Carry carefully back to the laboratory without shaking, and place for twenty-four hours in a cool place, preferably an ice chest. The clear serum will separate from the clotted blood. With a sterile 10 c.c. pipette, transfer this quantity of serum to each of a series of test-tubes which must previously have been sterilised by dry heat. The serum may, with all precautions, have been contaminated during the manipulations, and must be sterilised. As it will coagulate if heated above 68° C., advantage must be taken of the intermittent process of sterilisation at 57° C. (Method B 4). It is therefore kept for one hour at this temperature on each of eight successive days. It is always well to incubate it for a day at 37° C. before use, to see that the result is successful. After sterilisation it is then "inspissated," by which process a clear solid medium is obtained. "Inspissation" is probably an initial stage of coagulation, and is effected by keeping the serum at 65° C. till it stiffens. This temperature is just below the coagulation point of the serum. The more slowly the operation is performed the clearer will be the serum. The apparatus used is seen in Fig. 8. It consists of a rectangular, shallow, covered, hot-water jacket, which can be rapidly heated by an **S**-shaped Bunsen containing many lateral perforations, from each of which a flame issues. The apparatus rests on four legs, the front two of which can be shortened, and thus the whole tilted forward. Tubes containing a suitable quantity of serum can thus

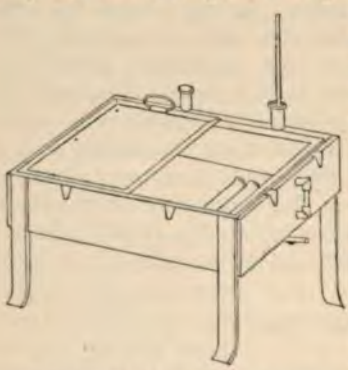

FIG. 8.—Blood serum inspissator.

be laid on their sides without the contents reaching as high as the plug. The serum tubes being thus placed, and the temperature being raised to 65° C., the contents solidify in a sloped position in the interior. It is well not only to have the jacket filled with water, but also to put some water in the trough in which the tubes lie, (and also to have a thermometer in the latter). This prevents cooling of the tubes when the lid is raised to see if the process is complete. It is evident that this medium is tedious to prepare, but it was necessary as long as no other means for growing the tubercle bacillus was known. Pleuritic and other effusions may be prepared in the same way, and used as media, but care must be taken in their use, as we have no right to say that pathological effusions have the same chemical composition as normal serum.

If blood be collected with strict aseptic precautions, then sterilisation of the serum is unnecessary. To this end the mouth of the cylinder used for collecting the blood, instead of being plugged with wool, has an india-rubber bung inserted in it through which two bent glass tubes pass. The outer end of one of these is of convenient length and, before sterilisation, a large cap of cotton wool is tied over it; the other tube is plugged with a piece of cotton wool. In the slaughter-house the cap is removed and the tube is inserted into the blood vessel as a cannula. The cylinder is thus easily filled. Another method is to conduct the blood to the cylinder by means of a sterilised cannula and india-rubber tube, the former being inserted in the blood vessel. The serum obtained under such circumstances must be incubated before use, to make sure that it is sterile.

Alkaline Blood Serum (Lorrain Smith's Method).—To each 100 c.c. of the serum obtained as before, add 1-1.5 c.c. of a 10 per cent solution of sodium hydrate and shake it gently. Put sufficient of the mixture into each of a series of test-tubes, and laying them on their sides, sterilise by method B (2). If the process of sterilisation be carried out too quickly, bubbles of gas are apt to form before

the serum is solid, and these interfere with the usefulness of the medium. Dr. Smith informs us that this can be obviated if the serum be solidified high up in the Koch's steriliser, in which the water is allowed only to simmer. In this case sterilisation ought to go on for one and a half hours. A clear solid medium (consisting practically of alkali albumin) is thus obtained, and he has found it of value for the growth of the organisms for which Koch's serum is used, and especially for the growth of the B. diphtheriæ. Its great advantage is that aseptic precautions in obtaining blood from the animal are not necessary, and it is easily sterilised.

Marmorek's Serum Media.—There has always been a difficulty in maintaining the virulence of cultures of the pyogenic streptococci, but Marmorek has succeeded in doing so by growing them on the following media, which are arranged in the order of their utility :—

1. Human serum 2 parts, bouillon 1 part.
2. Pleuritic or ascitic serum 1 part, bouillon 2 parts.
3. Asses' or mules' serum 2 parts, bouillon 1 part.
4. Horse serum 2 parts, bouillon 1 part.

Human serum can be obtained from the blood shed in venesection, the same precautions being taken as in the case of that got in the slaughter-house. In the case of these media, sterilisation is effected by method B 4, and they are used fluid.

Potatoes as Culture Material.

(*a*) **In Potato Jars.**—The jar consists of a round, shallow, glass vessel with a similar cover (*vide* Fig. 9). It is washed with 1-1000 corrosive sublimate, and a piece of circular filter paper, moistened with the same, is laid in its bottom. On this latter are placed four sterile watch glasses. Two firm, healthy, small, round potatoes, as free from eyes as possible, and with the skin whole, are scrubbed well with a nail brush under the tap and steeped for two to three hours in 1-1000 corrosive sublimate. They are placed in a

and steamed in the Koch's steriliser for thirty or longer. When cold, each is grasped between thumb and forefinger ıave been sterilised with te) and cut through the with a sterile knife. It o have the cover of the d by an assistant, and rm the cutting beneath h half is put in one of h glasses, the cut sur- vhich are then ready ulation with a bacterial growth, being uppermost. Smaller jars, each of which holds half of a potato, are also used in the same way and are very convenient.

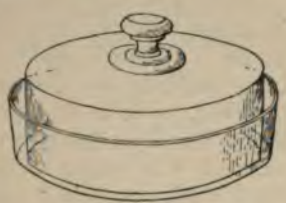

FIG. 9.—Potato jar.

10. — Cylinder o cut obliquely.

(*b*) **By Slices in Tubes.** —This method, introduced by Ehrlich, is the best means of utilising as a medium. A large, long potato is hed and scrubbed, and peeled with a ife. A cylinder is then bored from its with an apple corer or a large cork nd is cut obliquely, as in Fig. 10. dges are thus obtained, each of which d broad end down in a test-tube of form (see Fig. 11). In the wide part ottom of this tube is placed a piece of vool, which catches any condensation hich may form. The wedge rests on striction above this bulbous portion. oes, washed, dried, and with cotton the bottom and in the mouth, are l before the slices of potato are ed. After the latter are inserted, the e steamed in the Koch steam steriliser for one An ordinary test-tube may be used with a piece

FIG. 11. — Ehrlich's tube containing piece of potato.

of sterile absorbent wool in its bottom, on which the potato may rest.

The use of the potato as a medium is very important, as in certain cases the growths of bacteria on it are very characteristic. Potatoes ought not to be prepared long before being used, as the surface is apt to become dry and discoloured. It is well to take the reaction of the potato with litmus before sterilisation, as this varies; normally in young potatoes it is weakly acid. Sometimes it is necessary to make it alkaline, which may be done by steeping for a few minutes in a very weak soda solution. Potatoes before being inoculated ought always to be incubated at 37° C. for a night, to make sure that their sterilisation has been successful.

Bread Paste.

This is useful for growing torulæ, moulds, etc. Some ordinary bread is cut into slices, and then dried in an oven till it is so dry that it can be pounded to a fine powder in a mortar, or rubbed down with the fingers and passed through a sieve. Some 100 c.c. flasks are washed, dried, and sterilised, and a layer of the powder half an inch thick placed on the bottom. Distilled water, sufficient to cover the whole of it, is then run in with a pipette held close to the surface of the bread, and, the cotton-wool plugs being replaced, the flasks are sterilised in the Koch's steriliser by method B (2). The reaction is slightly acid.

The Use of the Culture Media.

The culture of bacteria is usually carried on in test-tubes conveniently 6 × $\frac{5}{8}$ in. If new, these ought to be carefully washed and dripped, their mouths plugged with pledgets of plain cotton wool and sterilised for one hour at 170° C. The reason is that the glass, being usually packed in straw, is covered with the extremely resisting spores of the bacillus subtilis. Tubes which have been in use are merely well washed, dried thoroughly, and plugged.

Cotton-wool plugs are universally used for protecting the sterile contents of flasks and tubes from contamination with the bacteria of the air. The contained air passes through the plug during sterilisation; what passes back on cooling is filtered free of germs by the wool. A medium

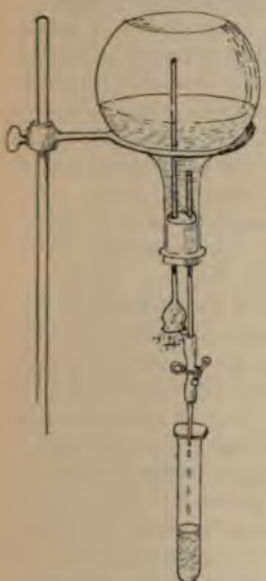

FIG. 12.—Apparatus which may be used for filling tubes. The apparatus explains itself. The india-rubber stopper with its tubes ought to be sterilised before use.

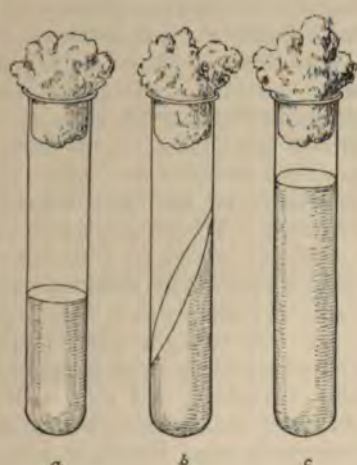

FIG. 13.—Tubes of media.

a. Ordinary upright tube. *b*. Sloped tube. *c*. "Deep" tube for cultures of anærobes.

thus protected will remain sterile for years. Whenever a protecting plug is removed for even a short time, the sterility of the contents is endangered. It is well to place the bouillon, gelatine, and agar media in the test-tubes directly after filtration. The media can then be sterilised in the test-tubes.

In filling tubes, care must be taken to run the liquid down the centre, so that none of it drops on the inside of the upper part of the tube with which the cotton-wool plug will be in contact, otherwise the latter will subsequently stick to the glass and its removal will be difficult. The tubes may, when filled, be placed in cages made of fine wire gauze and sterilised. If all the contents of a flask of medium be not filled into tubes, the remainder must be re-sterilised before being stored. In the case of liquid media, test-tubes are filled about one-third full. With the solid media the amount varies. In the case of gelatine media, tubes filled one-third full and allowed to solidify while standing upright, are those commonly used. With organisms needing an abundant supply of oxygen the best growth takes place on the surface of the medium, and for practical purposes the surface ought thus to be as large as possible. To this end "sloped" agar and gelatine tubes are used. To prepare these, tubes are filled only about one-sixth full, and after sterilisation are allowed to solidify, lying on their sides with their necks supported so that the contents extend 3 to 4 inches up, giving an oblique surface when held upright after solidification. Thus agar is commonly used in such tubes (less frequently gelatine is also "sloped"), and this is the position in which blood serum is inspissated. Tubes, especially those of the less commonly used media, should be placed in large jars provided with stoppers, otherwise the contents are apt to evaporate. A tube of medium which has been inoculated with a bacterium, and on which growth has taken place, is called a "culture." A "pure culture" is such that only one organism is present. The methods of obtaining pure cultures will presently be described. They vary according as we are dealing with aërobic or anærobic organisms. When a fresh tube of medium is inoculated from an already existing culture, the resulting growth is said to be a "sub-culture" of the first. All manipulations involving the transference of small portions of growth either from one medium to another, as in the inoculation of tubes, or, as

will be seen later, to cover-glasses for microscopic examinations, are effected by pieces of platinum wire (No. 12 English gauge, .02 French gauge) fixed in glass rods 8 inches long. Every worker should have three such wires. Two are $2\frac{1}{2}$ inches long, one of these being straight (Fig. 14, *c*), and the other having a loop turned upon it (Fig. 14, *b*). The latter is referred to as the platinum "loop" or platinum "eyelet," and is used for many purposes. "Taking a loopful" is a phrase constantly used. The third wire (Fig. 14, *a*) ought to be $4\frac{1}{2}$ inches long and straight. It is used for making anærobic cultures. Cultures on a solid medium are referred to

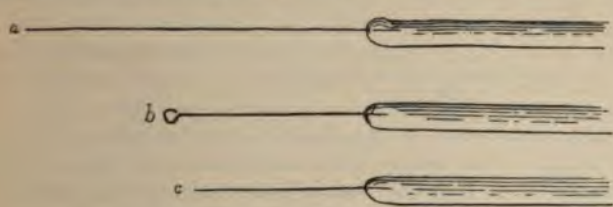

FIG. 14.—Platinum wires in glass handles.

c. Straight needle for ordinary puncture inoculations. *b*. "Platinum loop." *a*. Long needle for inoculating "deep" tubes.

(1) as "puncture" or "stab" cultures (German, Stichkultur), or (2) as "stroke" cultures (Strichkultur), according as they are made (1) on tubes solidified in the upright position, or (2) on sloped tubes.

To inoculate say one ordinary upright gelatine tube from another, the two tubes are held in an inverted position between the forefinger and thumb of the left hand with their mouth towards the person holding them; the plugs are twisted round once or twice to make sure they are not adhering to the glass. The short, straight platinum wire is then heated to redness from point to insertion, and 2 to 3 inches of the glass rod are also passed two or three times through the Bunsen flame. It is held between the right fore and middle fingers, with the needle projecting

backwards, *i.e.* away from the right palm. Remove plug from culture with right forefinger and thumb, and continue to hold it between the same fingers. Now touch the culture with the platinum needle, and, withdrawing it, replace plug. In the same way remove plug from tube to be inoculated, and plunge platinum wire down the centre of the gelatine to within half an inch of the bottom. It must on no account touch the glass above the medium. The wire is then immediately sterilised. The sub-culture is labelled, and in a bacteriological laboratory a label should never be licked. If one or other tube contain a liquid medium, it must be held bottom downwards between the same fingers. When a stroke culture is made the same manipulations are gone through. Here the platinum loop is used, and a little of the culture is smeared in a line along the surface of the medium from below upwards. In inoculating tubes, it is always well, on removing the plugs to make sure that no strands of cotton fibre are adhering to the inside of the necks. As these might be touched with the charged needle and the plug thus be contaminated, they must be removed by heating the inoculating needle red-hot and scorching them off with it. When the platinum

FIG. 15.—Another method of inoculating solid tubes.

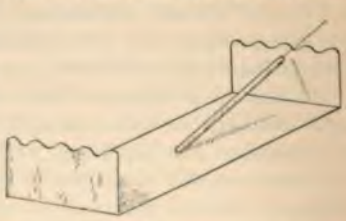

FIG. 16.—Rack for platinum needles.

wires are not in use they may be laid in a rack made by bending up the ends of a piece of tin, as in Fig. 16. Before commencing inoculation manipulations, this rack ought to be sterilised by passing it several times through the flame.

The Methods of the Separation of Aërobic Organisms.

The general principle underlying the methods of separation is the dilution of the bacterial mixture, till each microbe is sufficiently separated from its neighbours to allow it to multiply into a growth (called a "colony"), without the latter coming in contact with the colonies produced by other microbes present. In order to render the colonies easily accessible, the medium is made to solidify in as thin a layer as possible, by being poured out on glass plates.

As the optimum temperatures of organisms vary, it is necessary to adapt to the process a low melting-point medium, such as gelatine, and a high melting-point medium, such as agar. Many pathogenic organisms, *e.g.*, pneumococcus, B. diphtheriæ, etc., grow too slowly on gelatine to allow its ready use. On the other hand, many organisms, *e.g.*, some occurring in water, do not develop on agar incubated at 37° C.

Separation by Gelatine Media.—With both the gelatine and agar media the fluid medium containing bacilli is poured out on plates of glass, and, therefore, when growth takes place, "plate cultures" are said to be obtained. Either simple plates of glass 4 inches by 3 inches are used, or, what are more convenient, circular glass cells with similar overlapping covers. The latter are known as Petri's dishes or capsules (Fig. 17). They are usually 3 inches in diameter and half an inch deep. The advantage of these is that they do not require to be kept

FIG. 17.—Petri's capsule. (Cover shown partially raised.)

absolutely level while the medium is solidifying, and can be readily handled afterwards without admitting impurities. Whether plates or capsules are used, they are washed, dried with a clean cloth, and sterilised for one hour in dry air at 170° C., the plates being packed in sheet-iron boxes made for the purpose (see Fig. 18).

1. *Glass Plates* (Koch).—When plates of glass are to be used, an apparatus on which they may be kept level while the medium is solidifying is, as has been said, necessary. An apparatus devised by Koch is used (Figs. 18, 19). This

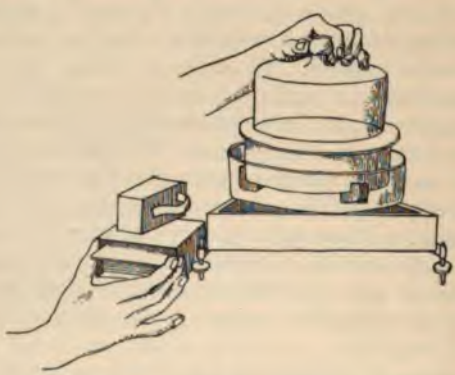

FIG. 18.—Koch's levelling apparatus for use in preparing plates. Hands shown in first position for transferring sterile plate from iron box to beneath bell jar, where it subsequently has the medium poured out upon it.

consists of a circular plate of glass (with the upper surface ground, the lower polished) on which the plate used for pouring out the medium is placed. The latter is protected from the air during solidification by a bell jar. The circular plate and bell jar rest on the flat rim of a circular glass trough, which is filled quite full with a mixture of ice and water to facilitate the lowering of the temperature of whatever is placed beneath the bell jar. The glass trough rests on corks on the bottom of a larger circular trough,

which catches any water which may be spilled. This trough in turn rests on a wooden triangle with a foot at each corner, the height of which can be adjusted, and which thus constitutes the levelling apparatus. A spirit level is placed where the plate is to go, and the level of the ground glass plate thus assured. There is also prepared a "damp chamber," in which the plates are to be stored after being made. This consists of a circular glass trough with a similar cover. It is sterilised by being washed outside and inside with the perchloride of mercury 1-1000, and a circle of filter paper moistened with the same is laid on its bottom. Glass benches on which the plates may be laid are similarly purified. Three gelatine tubes, marked *a*, *b*, *c*,[1] are now liquefied by placing in a beaker of water at any temperature between 25° C. and 38° C. Inoculate *a* with the bacterial mixture. The amount of the latter to be taken varies. If the microscope shows enormous numbers of different kinds of bacteria present, just as much as adheres to the point of a straight platinum needle is sufficient. If the number of bacilli is small, one to three loops of the mixture may be transferred to the medium. Shake *a* well, but not so as to cause many fine air-bubbles to form. Transfer two loops of gelatine from *a* to

FIG. 19. — Koch's levelling apparatus. Hands shown in second position just as the plate is lowered on to the ground glass surface. By executing the transference of the plate from the box in this way, the surface which was undermost in the latter is uppermost in the leveller, and thus never meets a current of air which might contaminate it.

[1] For marking glass vessels it is convenient to use the red, blue, or yellow pencils made for the purpose by Faber.

b. Shake *b* and transfer two loops to *c*. The plugs of the tubes are in each case replaced and the tubes returned to the beaker. The hands having been washed in perchloride of mercury 1-1000 and dried, the plate box is opened, and a plate lifted by its opposite edges and transferred to the levelled ground glass (as in Fig. 19). The plug of tube *a* is now removed and the mouth of the tube passed two or three times through the Bunsen flame, the tube being meantime rotated round a longitudinal axis. Any organisms on its rim are thus killed. The bell jar of the leveller being now lifted a little, the gelatine is poured out on the surface of the sterile plate, and while still fluid, is spread by stroking with the rim of the tube. The plate is now transferred to the moist chamber as rapidly as possible, so as to avoid atmospheric contamination. To do this, one of the benches is put on the top of the chamber. The top is then lifted off and placed on the table near the leveller. The plate is then quickly transferred to the bench. The latter is lifted by its ends and placed at the bottom of the moist chamber, the top of which is now replaced. Tubes *b* and *c* are similarly treated, and the resulting plates stacked in series on the top of *a*. The chamber is labelled and set aside for a few days till the appearance of the colonies as little grey or coloured points on the plates, indicates that growth has taken place. Very often from such naked-eye appearances as colour, contour, shape, liquefaction or non-liquefaction of the gelatine, these colonies can be classified into groups. Further aid is obtained by examination with a magnifying glass or a low-power microscopic lens. Their character is ultimately settled by making film preparations for examination with higher powers. During this process of classifying the colonies, the plate must be kept covered in the moist chamber as much as possible. When the grouping is completed, gelatine tubes are inoculated from a colony of each group, and the different organisms present capable of growing on gelatine, are thus separated. The cultures obtained can then be investigated,

first as to their purity and then with a view to their identification.

2. *Glass Capsules.*—While in certain circumstances, as when the number of colonies has to be counted, it is best to use plates, in the usual laboratory routine Petri's capsules are to be preferred. The technique of the inoculation of the tubes is, of course, the same. The contents of the tubes are then poured out into three capsules, and these are labelled. Not only is it not necessary to use the leveller, but the risk of atmospheric contamination is less than with plates, as the cover of the capsule is lifted only sufficiently to allow the gelatine to be poured in, and the latter is thus practically not exposed to the air at all. In examining a capsule when growth has taken place, it can be held up to the light with cover *in situ*, and the colonies observed; and, further, it can be turned upside down on the stage of the microscope, and the colonies examined with a low power through the bottom.

As the naked-eye and microscopic appearances of colonies are often very characteristic, plate cultures, besides use in separation, are often taken advantage of in the description of individual organisms. The plate-culture method can also be used to test whether a tube culture is or is not pure. The suspected culture is plated (three plates being prepared as usual). If all the colonies are the same, then the cultures may be held to be pure.

FIG. 20. — Tube for Esmarch's roll culture.

3. *Esmarch's Roll Tubes.*—Here the principle is that of dilution as before. In each of three test-tubes $1\frac{1}{4}$ or $1\frac{1}{2}$ inch in diameter, gelatine to the depth of $\frac{3}{4}$ of an inch is placed. These are sterilised. The gelatine is melted and inoculated with the bacterial mixture as in making plate cultures, but instead of being poured out it is rolled in a nearly horizontal

position under a cold tap till it solidifies as a uniformly thin layer on the inside of the tube. Practically we deal with a cylindrical plate of gelatine instead of a flat one. A convenient form of tube for this method is one with a constriction a short distance below the plug of cotton wool (Fig. 20). The great disadvantage of the method is, that if organisms liquefying the gelatine be present, the liquefied gelatine contaminates the rest of the plate.

Separation by Agar Media—1. *Agar Plates.*—The only difference between the technique here and that with gelatine, depends on the difference in the melting points of the two media. Agar, we have said, melts at 98° C., and becomes again solid a little under 40° C. As it is dangerous to expose organisms to a temperature above 42° C., it is necessary in preparing tubes of agar to be used in plate cultures to first melt them, by boiling in a vessel of water for a few minutes, and then to cool them to about 42° C. before inoculating. The manipulation here must be rapidly carried out, as the margin of time, before solidification occurs, is narrow; otherwise the details are the same as for gelatine. Esmarch's tubes are not suitable for use here, as the agar does not adhere well to the sides. If agar have 2 per cent of a strong watery solution of pure gum arabic added, Esmarch's tubes may, however, be used.

2. *Separation by Stroking Mixture on Surface of Agar Media.*—The bacterial mixture, instead of being mixed in the medium, is spread out on its surface. The method may be used both when the bacteria to be separated are in a fluid, and when contained in a fairly solid tissue or substance, such as a piece of diphtheritic membrane. In the case of a tissue, for example, a small portion entangled in the loop of a platinum needle is stroked in successive parallel longitudinal strokes on sloped agar, the same aspect being brought in contact with the agar in all the strokes. Three strokes may be made on each tube, and three tubes are usually sufficient. In this process the organisms on the surface of the tissue are gradually rubbed off, and when growth has taken place it will be found that

in the later strokes the colonies are less numerous than in the earlier, and sufficiently far apart to enable parts of them to be picked off without the needle touching any but one colony. When, as in the case of diphtheria membrane, putrefactive organisms are likely to be present on the surface of the tissue, these can be in great part removed by washing it well in cold water previously sterilised (*vide* Diphtheria). In the case of liquids, the loop is charged and similarly stroked. Tubes thus inoculated must be put in the incubator in the upright position and must be handled carefully, so that the condensation water, which always is present in incubated agar tubes, may not run over the surface. Agar, poured out in a Petri's capsule and allowed to stand till firm, may be used instead of successive tubes. Here a sufficient number of strokes can be made in one capsule. Sloped inspissated blood-serum tubes may be used instead of agar. The method is rapid and easy, and gives good results.

Separation of Pathogenic Bacteria by Inoculation of Animals.—It is found difficult and often impossible to separate by ordinary plate methods certain pathogenic organisms, such as B. tuberculosis, B. mallei, and the pneumococcus, when these occur in conjunction with other bacteria. These grow best on special media, and the first two (especially the tubercle bacillus) grow so slowly that the other organisms present outgrow them, cover the whole plates, and make separation impossible. The method adopted in such cases is to inoculate an animal with the mixture of bacilli, wait until the particular disease develops, kill it, and with all aseptic precautions (*vide* p. 115) inoculate tubes of suitable media from characteristic lesions situated away from the seat of inoculation, *e.g.* from spleen in the case of B. tuberculosis, spleen or liver in the case of B. mallei, and heart blood in the case of pneumococcus.

Separation by killing Non-spored Forms by Heat.—This is a method which has a limited application. As has been said, the spores of a bacterium resist heat more than the vegetative forms. If there is a mixture containing spores of

one bacterium and vegetative forms of this and other bacteria, then if the mixture be boiled for a few minutes all the vegetative forms will be killed, while the spores will remain alive and will develop subsequently. This method can be easily tested in the case of cultivating B. subtilis from hay infusion. A little chopped-up hay is placed in a flask of water, which is boiled for about ten minutes. On this being allowed to cool and stand, in a day or two a scum forms on the surface, which is found to be a pure culture of the bacillus subtilis. The method is also often used to aid in the separation of B. tetani, *vide infra.*

The Principles of the Culture of Anærobic Organisms.

All ordinary media, after preparation, may contain traces of free oxygen, and will absorb more from the air on standing. (1) For the growth of anærobes this oxygen may be expelled by the prolonged passing of an inert gas, such as hydrogen, through the medium (liquefied if necessary). Further, the medium must be kept in an atmosphere of the same gas, while growth is going on. (2) Media for anærobes may be kept in contact with the air, if they contain a reducing agent which does not interfere with bacterial growth. Such an agent takes up any oxygen which may already be in the medium, and prevents further absorption. The reducing body used is generally glucose. Formate of sodium may be employed. The preparation of such media has already been described (pp. 43-46). In this case the medium ought to be of considerable thickness.

The Supply of Hydrogen for Anærobic Cultures.—The gas is generated in a large Kipp's apparatus from pure sulphuric acid and pure zinc. It is passed through three wash bottles as in Fig. 21. In the first is placed a solution of lead acetate (1 in 10 of water) to remove any traces of sulphuretted hydrogen. In the second is placed a 1 in 10 solution of silver nitrate to remove any arsenietted

hydrogen which may be present if the zinc is not quite pure. In the third is a solution of pyrogallic acid in caustic potash (1 in 10) to remove any traces of oxygen. The tube leading from the last bottle to the vessel containing the medium ought to be sterilised by passing through a Bunsen flame, and should have a small plug of cotton wool in it to filter the hydrogen germ-free.

The removal of the air from an apparatus used in anærobic culture may be accelerated by sucking the air

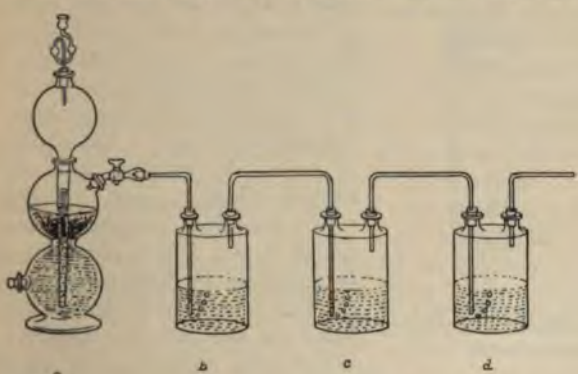

FIG. 21.—Apparatus for supplying hydrogen for anærobic cultures.

a. Kipp's apparatus for manufacture of hydrogen. *b*. Wash-bottle containing 1-10 solution of lead acetate. *c*. Wash-bottle containing 1-10 solution of silver nitrate. *d*. Wash-bottle containing 1-10 solution of pyrogallic acid. (*b*, *c*, and *d* are intentionally drawn to a larger scale than *a* to show details.)

out of one end of it as well as supplying hydrogen by the other. The means adopted may be either an ordinary air-pump or a water-exhaust pump. The exhaust tube is connected with the tube by which under ordinary circumstances the hydrogen escapes (*e.g.*, Fig. 22, *i*). The inner end of this tube must of course be above the level of any contained liquid. Such a procedure in actual practice is rarely necessary.

Separation of Anærobic Organisms.—(*a*) In glucose gelatine. A $1\frac{1}{4}$ inch test-tube has as much gelatine put

into it as would be used in the Esmarch roll-tube method. It is corked with an india-rubber stopper having two tubes passing through it, as in Fig. 22. The ends of the tubes are partly drawn out as shown, and covered with plugs of cotton wool. Three such tubes are prepared, and they are sterilised in the steam steriliser (p. 37). After sterilisation the gelatine is melted and one tube inoculated with the mixture containing the anærobes; the second is inoculated from the first, and the third from the second, as in making ordinary gelatine plates. After inoculation the gelatine is kept liquid by the lower ends of the tubes being kept in water at about 30° C., and hydrogen is passed in through tube *x* for twenty minutes. The gas-supply tubes are then completely sealed off at *x* and *i*, and each test-tube is rolled as in Esmarch's method till the gelatine solidifies as a thin layer on the internal surface. A little hard paraffin may be run between the rim of the test-tube and the stopper, and round the perforations for the gas-supply tubes, to ensure that the apparatus is air-tight. The gelatine is thus in an atmosphere of hydrogen in which the colonies may develop. The latter may be examined and isolated in a way which will be presently described. The method is admirably suited for all anærobes which grow at the ordinary temperature.

FIG. 22.—Esmarch's roll-tube adapted for culture containing anærobes.

(*b*) In glucose agar (Vignal's method). Three pieces of ordinary quill-tubing (bore about $\frac{1}{8}$ inch) about a foot long are taken, the ends are tapered in the gas flame, and they are sterilised either by method A (2) (p. 36), or simply by passing backwards and forwards through the flame till they are very hot. Three ordinary test-tubes, *a*, *b*, *c*, of glucose agar are now boiled in a beaker, cooled to 42° C., and inoculated with the bacterial mixture as for plate

cultures, *i.e.*, *b* from *a* and *c* from *b*. A current of hydrogen being passed through the pieces of quill-tubing to expel the air, the contents of each of the test-tubes are now sucked up with the mouth into one of the quill-tubes and both the ends of the latter sealed off in the flame. The agar will solidify *in situ* and the tubes may be incubated. The colonies will be observed as small grey specks. The tube in which these are farthest apart must be chosen, the glass notched with a file opposite to a colony to be examined, and the quill-tube broken. A tube of a suitable medium may now be inoculated with the growth. If there is any appearance of gas formation in the agar the tubes must be broken carefully, otherwise the contents may be ejected; for this reason it is desirable to take for examination a tube containing very few colonies. It is even better to use four tubes and make the dilution more complete.

Cultures of Anærobes.—When by one or other of the above methods separate colonies have been obtained, growth may be maintained on media in contact with ordinary air. The media must be those which contain reducing agents, and the test-tubes containing the medium must be filled to a depth of 4 inches. They are sterilised as usual and are called "deep" tubes. The long straight platinum wire is used for inoculating from a colony on a glucose gelatine roll-tube or a glucose agar quill-tube, and it is plunged well down into the "deep" tube. A little air gets into the upper part of the needle track, and no growth takes place there, but in the lower part of the needle track growth occurs. The needle may be prevented from carrying down air by melting the upper half-inch of the medium. This is easily effected with gelatine, but in the case of agar care must of course be taken to cool the part down to 42° C. In the case of agar it is better to liquefy the whole tube and cool the lower part until it is solid by putting it in water. From such "deep" cultures growths may be maintained indefinitely by successive sub-cultures in similar tubes.

Cultures of Anærobes in Liquid Media.—It is necessary

to employ such in order to obtain the toxic products of the growth of anærobes. Glucose broth is most convenient. It is placed either (1) in a conical flask with a lateral opening and a perforated india-rubber stopper, through which a bent glass tube passes, as in Fig. 23, *a*, by which hydrogen may be delivered, or (2) in a conical flask with a rubber stopper furnished with two holes, as in Fig. 23, *b*, through a tube in one of which hydrogen is delivered, while through the tube in the other the gas escapes. The inner end of the gas delivery tube must in either case be below the

FIG. 23.

a. Flask for anærobes in liquid media. Lateral nozzle and stopper fitted for hydrogen supply. *b*. A stopper arranged for a flask without lateral nozzle.

surface of the liquid, and the inner end of the lateral nozzle in the one case, and the inner end of the escape tube in the other, must of course be above the surface of the liquid. The single tube in the one case and the two tubes in the other ought to be partially drawn out in a flame to facilitate subsequent complete sealing. The ends of the tubes through which the gas is to pass have pieces of cotton wool tied on them. It is well previously to place in the tube, through which the hydrogen is to be delivered, a little plug of cotton wool. The flask being thus prepared, it is sterilised by methods B (2) or B (3). On cooling it is ready for inoculation. In the case of the flask with the

lateral nozzle, the cotton-wool covering having been momentarily removed, a wire charged with the organism is passed down to the bouillon. In the other kind of flask the stopper must be removed for an instant to admit the wire. The flask is then connected with the hydrogen apparatus by means of a short piece of sterile india-rubber tubing, and hydrogen is passed through for half an hour. In the case of flask (1), the lateral nozzle is plugged with molten paraffin covered with alternate layers of cotton wool and paraffin, the whole being tightly bound on with string. The entrance tube is now completely drawn off in the flame before being disconnected from the hydrogen apparatus. In the case of flask (2), first the exit tube and then the entrance tube are sealed off in the flame before the flask is disconnected from the hydrogen apparatus. It is well in the case of both flasks to run some melted paraffin all over the rubber stopper. Sometimes much gas is evolved by anærobes, and in dealing with an organism where this will occur, provision must be made for its escape. This is conveniently done by leading down the exit tube, and letting the end just dip into a trough of mercury (Fig. 24), or into mercury in a little bottle tied on to the end of the exit tube. The pressure of gas within causes an escape at the mercury contact, which at the same time acts as an efficient valve. The method of culture in fluid media is used to obtain the soluble products of such anærobes as the tetanus bacillus. In employing such a method the removal of the air may be accelerated by using an air-pump as described above.

FIG. 24.—Flask arranged for culture of anærobes which develop gas. *b* is trough of mercury into which exit tube dips.

Miscellaneous Methods.

Hanging-drop Cultures.—It is often necessary to observe micro-organisms alive, either to watch the method and rate of their multiplication, or to investigate whether or not they are motile. This is effected by making hanging-drop cultures. The method in the form to be described is only suitable for aërobes. For this special slides are necessary. Two forms are in use and are shown in Fig. 25. In A there is ground out on one surface a hollow having a

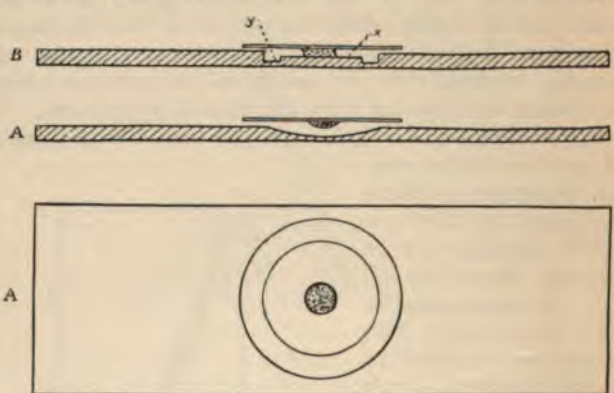

Fig. 25.

A. Hollow ground slide for hanging-drop cultures shown in plane and section.
B. Another form of slide for similar cultures.

diameter of about half an inch. That shown in B explains itself. The slide to be used and a cover-glass are sterilised by hot air in a Petri's dish, or simply by being heated in a Bunsen and laid in a sterile Petri to cool. In the case of A, one or other of two manipulation methods may be employed. (1) If the organism be growing in a liquid culture, a loop of the liquid is placed on the middle of the under surface of the sterile cover-glass, which is held in forceps, the points of which have been sterilised in a Bunsen flame. If the organism be growing in a solid medium, an

eyelet of sterile bouillon is placed on the cover-glass in the same position, and a *very* small quantity of the culture (picked up with a platinum needle) is rubbed up in the bouillon. The cover is then carefully lowered over the cell on the slide, the drop not being allowed to touch the wall or the edge of the cell. The edge of the cover-glass is covered with vaseline, and the preparation is then complete and may be placed under the microscope. If necessary, it may be first incubated and then examined on a warm stage. (2) The sterile cover-glass is placed on a sterile plate (an ordinary glass plate used for plate cultures is convenient). The drop is then placed on its *upper* surface, the details being the same as in the last case. The edge of the cell in the slide is then painted with vaseline, and the slide, held with the hollow surface downwards, is lowered on to the cover-glass, to the rim of which it of course adheres. The slide with the cover attached is then turned right side up, and the preparation is complete.

In the case of B the drop of fluid is placed on the centre of the table *x*. The drop must be thick enough to come in contact with the cover-glass when the latter is lowered on the slide, and not large enough to run over into the surrounding trench *y*. The cover-glass is then lowered on to the drop, and vaseline is painted along the margin of the cover-glass. The method of microscopic examination is described on page 83.

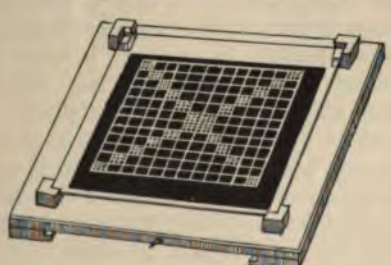

FIG. 26.—Apparatus for counting colonies.

The Counting of Colonies. — An approximate estimate of the number of bacteria present in a given amount of a fluid (say, water) can be arrived at by counting the number of colonies which develop when that amount is added to a tube of suitable

medium, and the latter plated and incubated. An ordinary plate should be used in such a case, and the medium poured out in as rectangular a shape as possible. For the counting, an apparatus such as is shown in Fig. 26 is employed. This consists of a sheet of glass ruled into squares as indicated, and supported by its corners on wooden blocks. The table to which these blocks are attached has a dark surface. The plate-culture containing the colonies is laid on the top of the ruled glass. The numbers of colonies in, say, twenty of the smaller squares are then counted, and an average struck. The total number of squares covered by the medium is then taken, and by a simple calculation the total number of colonies present can be obtained. Plate-cultures in Petri's dishes are sometimes employed for purposes of counting. The bottoms of such dishes are, however, never flat, and the thickness of the medium thus varies in different parts. If these dishes are to be used, a circle of the same size as the dish can be drawn with Chinese white on a black card, the circumference divided into equal arcs, and radii drawn. The dish is then laid on the card, the number of colonies in a few of the sectors counted, and an average struck as before. In counting colonies it is always best to aid the eye with a small hand lens.

The Bacteriological Examination of Water.—This may be undertaken with a view to finding either the number of bacteria present or the varieties present. In either case a small quantity ($\frac{1}{2}$ to 1 c.c.) is taken in a sterile pipette and added to a tube of gelatine, which is then plated and incubated at the room temperature. In case of water taken from a house tap, the latter should be made to run for several hours before the sample is taken, as water standing in pipes in a house is under very favourable conditions for multiplication of bacteria taking place, and if this precaution be not adopted, an altogether erroneous idea of the number present may be obtained. In the case of the examination of river water, the gelatine plates ought to be prepared on the spot; at any rate the time elapsing between the sample being taken and the plates being pre-

pared must be as short as possible, otherwise the bacteria will multiply, and again an erroneous idea of their number be obtained. When samples have to be taken for transport to the laboratory, these are best collected in four-ounce, wide-mouthed, stoppered bottles, which are to be sterilised by dry heat (the stopper must be removed during sterilisation, otherwise it will be tightly held by the neck of the bottle). In using such a bottle it is best to immerse it in the water, and then remove the stopper with forceps. Plates must be prepared from such a sample as soon as possible.

Filtration of Cultures.—For many purposes it is necessary to filter all the organisms from fluids in which they may have been growing. This is especially done in obtaining the soluble toxic products of bacteria. The only filter capable of keeping back such minute bodies as bacteria, is that formed from a tube of unglazed porcelain as introduced by Chamberland. There are several filters, differing slightly in detail, all possessing this common principle. Sometimes the fluid is forced through the porcelain tube. In one case the filter consists practically of an ordinary spigot screwed into the top of a porcelain tube. Through the latter the fluid is forced and finds itself in a chamber formed by a metal cylinder which surrounds the porcelain

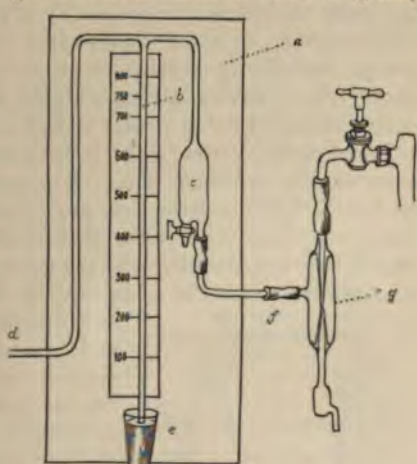

FIG. 27.—Geissler's vacuum pump arranged with manometer for filtering cultures. (The tap and pump are intentionally drawn to a larger scale than the manometer board to show details.)

tube. The fluid escapes by an aperture at the bottom. Such a filter is very suitable for domestic use, or for use in surgical operating-theatres. As considerable pressure is necessary, it is evident it must be put on a pipe leading directly from the main. Sometimes, when fluids to be filtered are very albuminous, they are forced through a porcelain cylinder by compressed carbonic acid gas. In ordinary bacteriological work, however, it is usually more convenient to suck the fluid through the porcelain by exhausting the air in the receptacle into which it is to flow. This is conveniently done by means of a Geissler's water-exhaust pump (Fig. 27, *g*), which must be fixed to a tap leading directly from the main. The connection with the tap must be effected by means of a piece of thick-walled rubber-tubing as short as possible, wired on to tap and pump, and firmly lashed externally with many turns of strong tape. Before lashing with the tape the tube may be strengthened by fixing round it with rubber solution strips of the rubbered canvas used for mending punctures in the outer case of a bicycle tyre. A manometer tube (*b*) and a receptacle (*c*) (the latter to catch any back flow of water from the pump if the filter accidentally breaks) are intercepted between the filter and the pump. These are usually arranged on a board *a*, as in Fig. 27. Between the tube *f* and the pump *a*, between the tube *d* and the filter, it is convenient to insert lengths of flexible lead-tubing connected up at each end with short, stout-walled rubber-tubing.

FIG. 28. — Chamberland's candle and flask arranged for filtration.

Various modifications of the filter are used. (*a*) An apparatus is arranged as in Fig. 28. The fluid to be filtered is placed in the cylindrical vessel *a*. Into this a "candle" or "bougie" of porcelain dips. From the upper end of the bougie a glass tube with thick rubber connections, as in Fig. 28, proceeds to

flask *b* and passes through one of the two perforations with which the rubber stopper of the flask is furnished. Through the other opening a similar tube proceeds to the exhaust-pump. When the latter is put into action the filtrate is sucked through the porcelain and passes over into flask *b*. This apparatus is very good, but not suitable for small quantities of fluid.

(*b*) A very good apparatus can be arranged with a lamp funnel and the porcelain bougie. These may be fitted up in

FIG. 29. — Chamberland's bougie arranged with lamp funnel for filtering a small quantity of fluid.

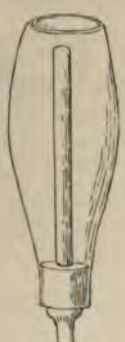

FIG. 30. — Bougie inserted through rubber stopper for same purpose as in Fig. 29.

two ways. (1) An india-rubber washer is placed round the bougie *c* at its glazed end (*vide* Fig. 29). On this the narrow end of the funnel *d*, which must, of course, be of an appropriate size, rests. A broad band of sheet rubber is then wrapped round the lower end of the funnel, and the projecting part of the bougie. It is firmly wired to the funnel above and to the bougie below. The extreme point of the latter is left exposed, and the whole apparatus, being supported on a stand, is connected by a glass tube with the lateral tube of the flask *b*; the tube *a* is connected with the exhaust-

pump. The fluid to be filtered is placed between the funnel and the bougie in the space *e*, and is sucked through into the flask *b*. (2) This modification is shown in Fig. 30. Into the narrow part of the funnel an india-rubber stopper is fitted, which has a perforation in it sufficiently large to receive the candle, which it should grasp tightly.

(*c*) Muencke's modification of the Chamberland principle is seen in Fig. 31. It consists of a thick-walled flask, *a*, the lower part conical, the upper cylindrical, with a strong flange on the lip. There are two lateral tubes, one horizontal to connect with exhaust-pump, and one sloping, by which the contents may be poured out. Passing into the upper cylindrical part of the flask is a hollow porcelain cylinder *b*, of less diameter than the cylindrical part of flask *a*. It is closed below, open above, and rests by a projecting rim on the flange of the flask, an asbestos washer, *c*, being interposed. The fluid to be filtered is placed in the porcelain cylinder, and the whole top covered, as shown at *f*, with an india-rubber cap with a central perforation; the tube *d* is connected with the exhaust-pump and the tube *e* plugged with a rubber stopper.

FIG. 31.—Muencke's modification of Chamberland's filter.

Before any one of the above apparatus is used, it ought to be connected up as far as possible and sterilised in the Koch's steriliser. The ends of any important unconnected parts ought to have pieces of cotton wool tied over them. After use the bougie is to be sterilised in the autoclave, and after being dried is to be passed carefully through a Bunsen flame, to burn off all organic

matter. If the latter is allowed to accumulate the pores become filled up.

The success of filtration must be tested by inoculating tubes of media from the filtrate, and observing if growth takes place, as there may be minute perforations in the candles sufficiently large to allow bacteria to pass through. Filtered fluids keep for a long time if the openings of the glass vessels in which they are placed are kept thoroughly closed. Sometimes the fluids may be evaporated to dryness in vacuo over sulphuric acid and kept in an air-tight bottle in a dry state.

Instead of being filtered off, the bacteria may be killed by various antiseptics, chiefly volatile oils, such as oil of mustard (Roux). These oils have no injurious effect on the chemical substances in the fluid, and they may be subsequently removed by evaporation. It is not practicable to kill the bacteria by heat when their soluble products are to be studied, as many of the latter are destroyed by a lower temperature than is required to kill the bacteria themselves.

The Storing and Incubation of Cultures.—Gelatine cultures must be grown at a temperature below their melting point, *i.e.* for 10 per cent gelatine, below 22° C. They are usually kept in ordinary rooms, which vary, of course, in temperature at different times, but which have usually a range of from about 12° C. to 18° C. Agar and serum media are usually employed to grow bacteria at a higher temperature, corresponding to that at which the organisms grow best, usually 37° C. in the case of pathogenic organisms. For the purpose of maintaining a uniform temperature incubators are used. These vary much in the details of their structure, but all consist of a chamber with double walls between which some fluid (water or glycerine and water) is placed, which, when raised to a certain temperature, ensures a fairly constant distribution of the heat round the chamber. The latter is also furnished with double doors, the inner being usually of glass. Heat is supplied from a burner fixed below. These burners vary

much in design. Sometimes a mechanism devised in Koch's laboratory is affixed, which automatically turns off the gas if the light be accidentally extinguished. Between the tap supplying the gas, and the burner, is interposed a gas regulator. Such regulators vary enormously in design, but for ordinary chambers which require to be kept at a constant temperature, Reichert's is as good and simple as any and is not expensive. It is shown in Fig. 32.

FIG. 32.—Reichert's gas regulator.

It consists of a long tube *f* closed at the lower end, open at the upper, and furnished with two lateral tubes. The lower part is filled with mercury up to above the level of the lower lateral tube. The end of the latter is closed by a brass cap through which a screw *d* passes, the inner end of which lies free in the mercury. The height of the latter in the perpendicular tube can thus be varied by increasing or decreasing the capacity of the lateral tube by turning the screw a few turns out of or into it. Into the upper open end of the perpendicular tube fits accurately a bent tube, *g*, drawn out below to a comparatively small open point *c*, and having in its side a little above the point called the peephole or bye-pass *e*. To fix the apparatus the long mercury bulb is placed in the jacket of the chamber to be controlled, tube *a* is connected to gas supply, tube *b* with the burner. The upper level of the mercury should be some distance below the lower open end of tube *c*. The burner is now lit. The gas passes in at *a* through *c* and *e* and out at *b* to the burner. When the thermometer in the interior of the chamber indicates that the desired temperature has been reached, the screw *d* is turned till the mercury reaches the end of the tube *c*. Gas can only now pass through the peephole *e*, and the flame goes down. The contents of the jacket cool, the mercury contracts off the end of tube *c*, and the flame rises. This alternation going on, the temperature of the chamber is kept very nearly constant. If the mercury cuts off the gas supply before the desired temperature is reached, and the screw *d* is as far out as it will go, then some of the mercury must be removed. Similarly, if when the desired temperature is reached and the screw *d* is as far in as it can go, the mercury does not reach *c*, some more must be introduced.

If the amount of gas which passes through the peephole is sufficient still to raise the temperature of the chamber when *c* is closed by the rise of the mercury, then the peephole is too large. Tube *c* must be unshipped and *e* plastered over with sealing-wax, which is pricked, while still soft, with a very fine needle. The gas flame, when only the peephole is supplying gas, ought to be sufficiently large not to be blown out by small currents of air.

The varieties of incubators are, as we have said, numerous. The most complicated and expensive are made by German manufacturers. Many of these are

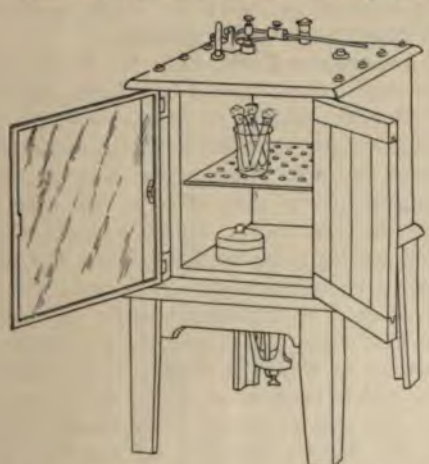

FIG. 33.—Hearson's incubator for use at 37° C.

unsatisfactory. They easily get out of order and are difficult to repair. We have found those of Hearson of London extremely good, and in proportion to their size much cheaper than the German articles. They are fitted with an admirable regulator. It is preferable in using an incubator to connect the regulator with the gas supply and with the Bunsen by flexible metal tubing. It is necessary to see that there is not too much evaporation from the surface of cultures placed within incubators, otherwise they may quickly dry up. It is thus advisable to raise the

amount of water vapour in the interior by having in the bottom of the incubator a flat dish full of water from which evaporation may take place. Tubes which will require to be long in the incubator should have their plugs covered either by india-rubber caps or by pieces of sheet rubber tied over them. These caps should be previously sterilised in 1-1000 corrosive sublimate and then dried. Before they are placed on the tubes the cotton-wool plug ought to be well singed in a flame. "Cool" incubators are often used for incubating gelatine at 21° to 22° C. Here again Hearson's design is as good as any in the market.

General Laboratory Rules.—On the working bench of every bacteriologist there should be a large dish of 1-1000 solution of mercuric chloride in water. Into this all tubes, vessels, plates, hanging-drop cultures, etc., which have contained bacteria and with which he has finished, ought to be at once plunged (in the case of tubes the tube and plug should be put in separately). On no account whatever are such infected articles to be left lying about the laboratory. The basin is to be repeatedly cleaned out. All the glass is carefully washed in repeated changes of tap water to remove the last trace of perchloride of mercury, a very minute quantity of which is sufficient to inhibit growth. Old cultures which have been stored for a time and from which fresh sub-cultures have been made ought to be steamed in the Koch's steriliser for two to three hours or in the autoclave for a shorter period and the tubes thoroughly washed out. Besides a basin of mercuric chloride solution for infected apparatus, etc., there ought to be a second reserved for the bacteriologist's hands in case of any accidental contamination of the latter. In making examinations of organs containing virulent bacteria, the hands should be previously dipped in 1-1000 mercuric chloride and allowed to remain wet with this solution. No food ought to be partaken of in the laboratory, and pipes, etc., are not to be laid with their mouth-pieces on the bench. No label is to be licked with the tongue. Before leaving the laboratory the bacteriologist ought to wash the

hands and forearms with 1-1000 mercuric chloride and then with yellow soap. In the case of any fluid containing bacteria being accidentally spilt on the bench or floor, 1-1000 mercuric chloride is to be at once poured on the spot. The air of the laboratory ought to be kept as quiet as possible.

CHAPTER III.

MICROSCOPIC METHODS — GENERAL BACTERIOLOGICAL DIAGNOSIS—INOCULATION OF ANIMALS.

The Microscope. — For ordinary bacteriological work a good microscope is essential. It ought to have a heavy stand, with rack and pinion and fine adjustment, a double mirror (flat on one side, concave on the other), a good condenser, with an iris diaphragm, and a triple nose-piece. It is best to have three objectives, either Zeiss A, D, and $\frac{1}{12}$ inch oil immersion, or the lenses of other makers corresponding to these. The oil immersion lens is essential. It is well to have two eye-pieces, say Nos. 2 and 4 of Zeiss or lenses of corresponding strengths. The student must be thoroughly familiar with the focusing of the light on the lens by means of the condenser, and also with the use of the immersion lens. It may here be remarked that when it is desired to bring out in sharp relief the margins of unstained objects, *e.g.*, living bacteria in a fluid, a narrow aperture of the diaphragm should be used, whereas, in the case of stained bacteria, when a pure colour picture is desired, the diaphragm ought to be widely opened. The flat side of the mirror ought to be used along with the condenser. When the observer has finished for the time being with his immersion lens he ought to wipe off the oil with a piece of silk or very fine washed linen. If the oil has dried on the lens it may be moistened with xylol—never with alcohol,

which will dissolve the material by which the lens is fixed in its metal carrier.

Microscopic Examination of Bacteria. 1. Hanging-drop Preparations.—Micro-organisms may be examined: (1) alive or dead in fluids; (2) in film preparations; (3) in sections of tissues. In the two last cases advantage is always taken of the affinity of bacteria for certain stains. When they are to be examined in fluids a drop of the liquid may be placed on a slide and covered with a cover-glass.[1] It is more usual, however, to employ hanging-drop preparations. The technique of making these has already been described. In examining them microscopically, it is necessary to use a very small diaphragm. It is best then to focus the edge of the drop with a low-power objective, and, arranging the slide so that part of the edge crosses the centre of the field, to clamp the preparation in this position. A high-power lens is then turned into position and lowered by the coarse adjustment to a short distance above its focal distance; it is now carefully screwed down by the fine adjustment, the eye being kept at the tube meanwhile. The shadow of the edge will be first recognised, and then the bacteria must be carefully looked for. Often a dry lens is sufficient, but for some purposes the oil immersion is required. If the bacteria are small and motile a beginner may have great difficulty in seeing them, and it is well to practise at first on some large form such as anthrax. In fluid preparations the natural appearance of bacteria may be studied, their rate of growth determined. The great use of such preparations, however, is to find whether or not the bacteria are motile, and for determining this point it is advisable to use either broth or agar cultures not more than twenty-four hours old. In the latter case a small fragment of growth is broken down in broth or in sterile water. Sometimes it is an advantage to colour the solution in which the hanging-drop is made up with a

[1] In bacteriological work it is essential that cover-glasses of No. 1 thickness (*i.e.*, .14 mm. thick) should be used, as those of greater thickness are not suitable for $\frac{1}{12}$ in. lens.

minute quantity of any aniline dye, say a small crystal of gentian violet to 100 c.c. of bouillon. Such a degree of dilution will not have any effect on the vitality of the bacteria. Ordinarily, living bacteria will not take up a stain, but even though they do not, the contrast between the unstained bacteria and the tinted fluid will enable the observer more easily to recognise the former.

2. **Film Preparations.**—This is the most extensively applicable method of microscopically examining bacteria. Fluids containing bacteria, such as blood, pus, scrapings of organs, can be thus investigated, as also cultures in fluid and solid media. The first requisite is a perfectly clean cover-glass. Many methods are recommended for obtaining such. The result can be in the great majority of cases obtained by the following procedure. The hands being washed clean with soap and water, a cover-glass is taken and a few drops of absolute alcohol or dilute acetic acid placed on it. The wet glass is then firmly rubbed between the right forefinger and thumb and then carefully dried with a perfectly clean duster. It is then placed in a pair of forceps (Cornet's pattern is very good, Fig. 34), and passed several times rapidly through a Bunsen flame, first the one side and then the other being downmost. By this means the last traces of dirt are burned off. The great difficulty in cleaning covers is to remove the last trace of grease. The test of this being accomplished is that, when the drop of fluid containing the bacteria is placed upon the glass, it can be uniformly spread with the platinum needle all over the surface without showing any tendency to retract into droplets. The best method, however, is that recommended by Van Ermengem. The cover-glasses are placed for some time in a mixture of concentrated sulphuric acid 6 parts, potassium bichromate 6 parts, water 100 parts, then washed thoroughly in water and kept in absolute alcohol.

FIG. 34.—Cornet's forceps for holding cover-glasses.

For use, a cover-glass is either dried by wiping with a clean duster or is simply allowed to dry. This method will amply repay the trouble, and really saves time in the end. A clean cover having been obtained, the film preparation can now be made. If a fluid is to be examined a loopful may be placed on the cover-glass, and either spread out over the surface with the needle, or another clean cover may be placed on the top of the first, the drop thus spread out between them and the two then drawn apart. When a culture on a solid medium is to be examined a loopful of distilled water is placed on the cover-glass and a minute particle of growth rubbed up in it and spread all over the glass. The great mistake made by beginners is to take too much of the growth. The point of the straight needle should just touch the surface of the culture, and when this is rubbed up in the droplet of water and the film dried, there should be an opaque cloud just visible on the cover-glass. When the film has been spread it must next be dried by being waved backwards and forwards at arm's-length above a Bunsen flame on the worker's bench. The film must then be fixed on the glass by being passed three or four times slowly through the flame. In doing this a good plan is to hold the cover-glass between the right forefinger and thumb; if the fingers just escape being burned no harm will accrue to the bacteria in the film.

In making films of a thick fluid such as *pus* it is best to spread it out on one cover with the needle. The result will be a film of irregular thickness, but sufficiently thin at many parts for proper examination. Scrapings of organs are very convenient if only the presence or absence of organisms is inquired after. Such scrapings may be smeared directly on the cover-glasses with or without the addition of sterile distilled water.

In the case of *blood*, a fairly large drop should be allowed to spread itself between two cover-glasses, which are then to be slipped apart, and being held between the forefinger and thumb are to be dried by a rapid to-and-fro movement in the air. A film prepared in this way may be

too thick at one edge, but at the other is beautifully thin. If it is desired to preserve the red blood-corpuscles in such a film it must be fixed by being placed in a hot-air chamber at 120° C. for half an hour, or in a saturated solution of corrosive sublimate for two or three minutes, then washed and dried. (Fig. 55 shows a film prepared by the latter method.) In the case of *urine*, the specimen must be allowed to stand, and films made from any deposit which occurs; or, what is still better, the urine is centrifugalised, and films made from the deposit which forms. Films dried and fixed by the above methods are now ready to be stained by the methods to be described below.

If it is desired to examine the fine histological structure of the cells of a discharge as well as to investigate the bacteria present, it is advisable to substitute "corrosive" films for the "dried" films, the preparation of which has been described. The initial stages in the preparation of corrosive films are the same as for other films, but instead of being dried in air they are placed, while still wet, film downwards on a saturated solution of perchloride of mercury in .75 per cent sodium chloride, in which they are allowed to remain for five minutes. They are then placed for half an hour, with occasional gentle shaking, in .75 per cent sodium chloride solution to wash out the corrosive sublimate. They are then passed through successive strengths of methylated spirit, being allowed to remain a few minutes in each. After this treatment they are stained and treated as if they were sections. The nuclear structure, mitotic figures, etc., are by this method well preserved, whereas these are considerably distorted in dried films.

Another excellent method of fixing film preparations is that devised by Gulland. The fixing solution has the composition—absolute alcohol, 25 c.c., pure ether, 25 c.c., alcoholic solution of corrosive sublimate (2 grm. in 10 c.c. of alcohol), about 5 drops. The films are placed, while still wet, in this solution for five minutes or longer. They are then washed well in water, and are ready for staining. A contrast stain can be applied at the same time as the

fixing solution, by saturating the 25 c.c. of alcohol with eosin before mixing. Thereafter the bacteria, etc., may be stained with methylene-blue or other stain, as described below. This method has the advantage over the previous that, as a small amount of corrosive sublimate is used, less washing is necessary to remove it from the preparation, and deposits are less liable to occur.

3. **Examination of Bacteria in Tissues.**—For the examination of bacteria in the tissues, the latter must be fixed and hardened, in preparation for being cut with a microtome. Fixation consists in so treating a tissue that it shall permanently maintain, as far as possible, the condition it was in when removed from the body. Hardening consists in giving such a fixed tissue sufficient consistence to enable a thin section of it to be cut. A tissue, after being hardened, may be cut in a freezing microtome, but far finer results can be obtained by embedding the tissue in solid paraffin and cutting with some of the more delicate microtomes of which, for pathological purposes, the small Cambridge rocker is by far the best. For bacteriological purposes embedding in celloidin is not advisable, as the celloidin takes on the aniline dyes which are used for staining bacteria, and is apt thus to spoil the preparation.

The Fixation and Hardening of Tissues. — *Absolute alcohol* may be used for the double purpose of fixing and hardening. If the piece of tissue is not more than $\frac{1}{8}$ inch in thickness it is sufficient to keep it in this reagent for one or two days. If the pieces are thicker a longer exposure is necessary, and in such cases it is better to change the alcohol at the end of the first twenty-four hours, as the first alcohol is diluted by water which comes out of the fluids of the tissue. The tissue must be tough without being hard, and the necessary consistence, as estimated by feeling with the fingers, can only be judged of after some experience. After hardening, the tissues may be placed in 50 per cent spirit till they are cut.

Corrosive sublimate is an excellent fixative agent. For this end a saturated solution in .75 per cent sodium chloride

solution is used. For small pieces of tissue $\frac{1}{8}$ inch in thickness, twelve hours' immersion is sufficient. If the pieces are larger, twenty-four hours is necessary. It is very important for the success of the subsequent procedures that the corrosive sublimate should be now thoroughly washed out of the tissues. They should be tied up in a piece of gauze, and this placed in a stream of running water for from twelve to twenty-four hours, according to the size of the pieces. They must then be placed for twenty-four hours in each of the following strengths of methylated spirit (free from naphtha [1]): 30 per cent, 60 per cent, and 90 per cent. Finally they are placed in absolute alcohol for twenty-four hours and are then ready to be prepared for cutting. If the tissue is very small, as in the case of minute pieces removed for diagnosis, the stages may be all compressed into twenty-four hours. In fact after fixation in corrosive the tissue may be transferred directly to absolute alcohol, the perchloride of mercury being removed after the sections are cut as will be afterwards described.

Methylated Spirit.—Small pieces of tissue may be placed in methylated spirit, which is to be changed after the first day. In six to seven days they will be hardened. If the pieces are large, a longer time is necessary.

The Cutting of Sections—1. *By Means of the Freezing Microtome.*—Pieces of tissue hardened by any of the above methods must have all the alcohol removed from them by washing in running water for twenty-four hours. They are then placed for from twelve to twenty-four hours (according to the size) in a thick syrupy solution containing two parts of gum arabic and one part of sugar. They are then cut on a freezing microtome (of which Cathcart's is a good example) and placed for a few hours in a bowl of water so that

[1] Ordinary commercial methylated spirit has wood naphtha added to it to discourage its being used as a beverage. The naphtha being insoluble in water a milky fluid results from the dilution of the spirit. By law chemists can only sell 8 ounces of pure spirit at a time. Most pathological laboratories are, however, licensed by the Excise to buy pure spirit in large quantities.

the gum and syrup may dissolve out. They are then stained or they may be stored in methylated spirit.

2. *Embedding and Cutting in Solid Paraffin.* — This method gives by far the finest results, and should always be adopted when practicable. The principle is the impregnation of the tissue with paraffin in the melted state. This paraffin when it solidifies gives support to all the tissue elements. The method involves that, after hardening, the tissue shall be thoroughly dehydrated, and then thoroughly permeated by some solvent of paraffin which shall expel the dehydrating fluid and prepare for the entrance of the paraffin. The solvents most in use are chloroform, cedar oil, xylol, and turpentine; of these chloroform and cedar oil are the best, the former being preferred as it permeates the tissue more rapidly. The more gradually the tissues are changed from reagent to reagent, in the processes to be gone through, the more successful is the result. A necessity of the process is an oven with hot-water jacket, in which the paraffin can be kept at a constant temperature just above its melting-point, a gas regulator, *e.g.*, Reichert's, being of course necessary. The tissues occurring in pathological work have a tendency to become brittle if overheated, and therefore the best results are not obtained by using paraffin melting about 58° C., such as is employed in most biological laboratories. We have used for some years a mixture of one part of paraffin, melting at 48°, and two parts of paraffin melting at 54° C. This mixture has a melting-point between 52° and 53° C., and it serves all ordinary purposes well. The finest quality of paraffin is that known as the "Cambridge paraffin," but many scientific-instrument makers supply paraffins which, for ordinary purposes, are quite as good, and much cheaper. The successive steps in the process of paraffin embedding are as follows :—

1. Pieces of tissue, however hardened, are placed in fresh absolute alcohol for twenty-four hours in order to their complete dehydration.

2. Transfer now to a mixture of equal parts of absolute alcohol and chloroform.

3. Transfer to pure chloroform for twenty-four hours. At the end of this time the tissues should sink or float heavily.

4. Transfer now to a mixture of equal parts of chloroform and paraffin and place on the top of the oven from twelve to twenty-four hours. If the temperature there is not sufficient to keep the mixture molten then they must be put inside.

5. Place in pure melted paraffin in the oven for twenty-four hours. For holding the paraffin containing the tissues small tin dishes such as are used by pastry-cooks will be found very suitable. There must be a considerable excess of paraffin over the bulk of tissue present, otherwise sufficient chloroform will be present to vitiate the final result and not give the perfectly hard block obtained with pure paraffin. With experience, the persistence of the slightest trace of chloroform can be recognised by smell.

In the case of very small pieces of tissue the time given for each stage may be much shortened, and where haste is desirable Nos. 2 and 4 may be omitted. Otherwise it is better to carry out the process as described.

6. Cast the tissues in blocks of paraffin as follows: Pairs of L-shaped pieces of metal made for the purpose by instrument makers must be at hand. By laying two of these together on a glass plate, a rectangular trough is formed. This is filled with fresh melted paraffin. In it is immersed the piece of tissue which is lifted out of its pure paraffin bath with heated forceps. The direction in which it is to be cut must be noted before the paraffin becomes opaque. When the paraffin has begun to set, the glass plate and trough have cold water run over them. When the block is cold, the metal L's are broken off and, its edges having been pared, it is stored in a pill-box.

Fixing of Sections on Slides.—Sections must be cut as thin as possible, the Cambridge rocking microtome being, on the whole, most suitable. They should not exceed 8 μ in thickness, and ought, if possible, to be about 4 μ. For their manipulation it is best to have two needles on handles,

FIG. 35.—Needle with square of paper on end for manipulating paraffin sections.

two camel's-hair brushes on handles, and a needle with a rectangle of stiff writing paper fixed on it as in the diagram (Fig. 35). When cut, sections are floated on the surface of a beaker of water kept at a temperature about 10° C. below the melting-point of the paraffin. On the surface of the warm water they become perfectly flat.

(*a*) *Fixation on Ordinary Slides. Gulland's Method.*—A supply of slides well cleaned being at hand, one of them is thrust obliquely into the water below the section, a corner of the section is fixed on it with a needle and the slide withdrawn. The surplus of water being wiped off with a cloth, the slide is placed on a support, with the section downwards, and allowed to remain on the top of the paraffin oven or in a bacteriological incubator from twelve to twenty-four hours. It will then be sufficiently fixed on the slide to withstand all the manipulations necessary during staining and mounting.

(*b*) *Fixation by Mann's Method.*—This has the advantage of being more rapid than the last. A solution of albumin is prepared by mixing the white of a fresh egg with ten parts of distilled water and filtering. Slides are made perfectly clean with alcohol. One is dipped into the solution and its edge is then drawn over one surface of another slide so as to leave on it a thin film of albumin. This is repeated with the others. As each is thus coated, it is leant, side smeared with the film downwards, on a ledge till dry and then the slides are stored in a wide stoppered jar till needed. The floating out is performed as before. The albuminised side is easily recognised by the fact that if it is breathed on, the breath does not condense on it. The great advantage of this method is that the section is fixed after twenty to thirty minutes' drying at 37° C.

Preparation of paraffin sections for staining.—Before staining, the paraffin must be removed from the section. This is best done by dropping on xylol out of a drop bottle. When the paraffin is dissolved out, the superfluous xylol is wiped off with a cloth and a little absolute alcohol dropped on. When the xylol is removed the superfluous alcohol is wiped off and a little 50 per cent methylated spirit dropped on. The sections are now ready to be stained. To save repetition we shall in treating of stains suppose that, with paraffin sections, these preliminary steps have already been taken, and further that sections cut by a freezing microtome are also in spirit and water. Deposits of crystals of corrosive sublimate often occur in sections which have been fixed by this reagent. These can be readily removed by placing the sections before staining for a few minutes in equal parts of Gram's iodine solution (*v. infra*) and water, and then washing in water containing a few drops of ammonia and finally in pure water.

Staining Principles.—To speak generally, the protoplasm of bacteria reacts to stains in a manner similar to the

nuclear chromatin, though sometimes more and sometimes less actively. The bacterial stains *par excellence* are the basic aniline dyes. These dyes are more or less complicated compounds derived from the coal-tar product aniline ($C_6H_5 . NH_2$). Many of them have the constitution of salts. Such compounds are divided into two groups according as the staining action depends on the basic or the acid portion of the molecule. Thus the acetate of rosaniline derives its staining action from the rosaniline. It is therefore called a basic aniline dye. On the other hand, ammonium picrate owes its action to the picric acid part of the molecule. It is therefore termed an acid aniline dye. These two groups have affinities for different parts of the animal cell. The basic stains have a special affinity for the nuclear chromatin, the acid for the protoplasm and various formed elements. Thus it is that the former—the basic aniline dyes—are especially the bacterial stains.

The number of basic aniline stains is very large. The following are the most commonly used :[1]—

Violet Stains.—Methyl-violet, R-5R (synonyms : Hoffmann's violet, dahlia).

Gentian-violet (synonyms : benzyl-violet, Pyoktanin).

Crystal-violet.

Blue Stains.—Methylene-blue[2] (synonym : phenylene-blue).

Victoria-blue.

Thionin-blue.

Red Stains.—Basic fuchsin (synonyms : basic rubin, magenta).

Safranin (synonyms : fuchsia, Giroflé).

Brown Stain.—Bismarck-brown (synonyms : vesuvin, phenylene-brown).

It is of the greatest importance that the stains used by the bacteriologist should be good, and therefore it is advisable to obtain those prepared by Grübler of Leipzig. One is then perfectly sure that one has got the right stain.

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[1] For further information on this subject the student is referred to Rawitz, "Leitfaden für histologische Untersuchungen," Jena, 1895, from which the following synonyms are taken.

[2] This is to be distinguished from methyl-blue which is a different compound.

Of the stains specified, the violets and reds are the most intense in action, especially the former. It is thus easy in using them to overstain a specimen. Of the blues, methylene-blue probably gives the best differentiation of structure, and it is difficult to overstain with it. Thionin-blue also gives good differentiation and does not readily overstain. Its tone is deeper than that of methylene-blue and it approaches the violets in tint. Bismarck-brown is a weak stain, but is useful for some purposes. Formerly it was much used in photomicrographic work, as it was less actinic than the other stains. It is not, however, needed now, on account of the improved sensitiveness of the plates.

It is most convenient to keep saturated alcoholic solutions of the stains made up, and for use to filter a little into about ten times its bulk of distilled water in a watch-glass. A solution of good body is thus obtained. Most bacteria (except those of tubercle, leprosy, and a few others) will stain in a short time in such a fluid. Watery solutions may also be made up, *e.g.* a saturated watery solution of methylene-blue or a 1 per cent solution of gentian-violet. Stains must always be filtered before use. Otherwise there may be deposited on the preparation granules which it is impossible to wash off. The violet stains in solution in water have a great tendency to decompose. Only small quantities should therefore be prepared at a time.

FIG. 36.—Syphon wash-bottle for distilled water used in washing preparations.

The Staining of Cover-glass Films.—Films are made from *cultures* as described above. The cover-glass may be floated on the surface of the stain in a watch-glass for about five minutes, or the cover-glass held in forceps with film side uppermost may have

as much stain poured on it as it will hold. When the preparation has been exposed for the requisite time, usually a few minutes, it is well washed in tap water in a bowl, or with distilled water with such a simple contrivance as that figured (Fig. 36). This consists of a jar set on a shelf above the bench. From it there proceeds a glass tube with a pointed nozzle by which the contents may be syphoned. The tube has near its lower end a piece of rubber tubing interposed, on which a clamp is fixed. When the film has been washed the surplus of water is drawn off with a piece of filter-paper, the preparation is carefully dried high over a flame, a drop of xylol balsam is applied, and the cover-glass mounted on a slide. Xylol balsam must be used for mounting all bacterial preparations. The reason is that xylol causes the colour to fade less than any other solvent of balsam. It is sometimes advantageous to examine films in a drop of water in place of balsam. The films can be subsequently dried and mounted permanently. In the case of tubercle, special stains are necessary (*v. infra*), but with this exception, practically all bacterial films made from cultures can be stained in this way. Some bacteria, *e.g.*, typhoid, glanders, take up the stains rather slowly, and for these the more intensive stains, red or violet, are to be preferred.

Films of *fluids from the body* (blood, pus, etc.) can be generally stained in the same way, and this is often quite sufficient for diagnostic purposes. The blue dyes are here preferable, as they do not readily overstain. In the case of such fluids, if the histological elements also claim attention it is best to use a blue which will stain the bacteria and the nuclei of the cells, and then after washing to stain the cellular protoplasm with a one to two per cent watery solution of eosin (which is an acid dye). In the case of films made from urine, where there is little or no albuminous matter present, the bacteria may be imperfectly fixed in the slide, and thus apt to be washed off. In such a case it is well to modify the staining method. A drop of stain is placed on a slide, and the cover-glass, film-side

down, lowered upon it. After the lapse of the time necessary for staining, a drop of water is placed at one side of the cover-glass and a little piece of filter-paper at the other side. The result is that the stain is sucked out by the filter-paper. By adding fresh drops of water and using fresh pieces of filter-paper, the specimen is washed without any violent application of water, and the bacteria are not displaced.

For the general staining of films a saturated watery solution of methylene-blue will be found to be the best stain to commence with.

The Use of Mordants and Decolorising Agents.—In films of blood and pus, and still more so in sections of tissues, if the above methods are used, the tissue elements may be stained to such an extent as to quite obscure the bacteria. Hence many methods have been devised in which the general principle may be said to be (*a*) the use of substances which, while increasing the staining power, tend to fix the stain in the bacteria, and (*b*) the subsequent treatment by substances which decolorise the overstained tissues to a greater or less extent, while they leave the bacteria coloured. The staining capacity of a solution may be increased—

(*a*) By the addition of substances such as carbolic acid, aniline oil, or metallic salts, all of which probably act as mordants.

(*b*) by the addition of alkalies, such as caustic potash or ammonium carbonate, in weak solution.

(*c*) By the employment of heat.

(*d*) By long duration of the staining process.

As decolorising agents we use chiefly mineral acids (hydrochloric, nitric, sulphuric), vegetable acids (especially acetic acid), and alcohol (either methylated spirit or absolute alcohol), or a combination of spirit and alcohol, *e.g.*, methylated spirit with a drop or two of hydrochloric acid added. In most cases about thirty drops of acetic acid in a bowl of water will be sufficient to remove the excess of stain from

over-stained films and sections. More of the acid may, of course, be added if necessary.

Hot water also decolorises to a certain extent, and over-stained films can be readily decolorised by placing a drop of water on the film and heating gently over a flame.

When preparations have been sufficiently decolorised by an acid, they should be well washed in tap water, or in distilled water with a little lithia carbonate added.

The methods embracing the use of a stain with a mordant, and a decoloriser, are very numerous, and we can only enumerate the best of them.

Dehydration and Clearing.—It is convenient, first of all, to indicate the final steps to be taken after a specimen is stained. We have already described the mounting of film preparations. *Sections* must be dehydrated, cleared, and then mounted in xylol balsam.

Dehydration is most commonly effected with absolute alcohol (it is economical to use first the cheaper methylated spirit, and then to finish up with alcohol, but this complication is hardly necessary). Alcohol, however, sometimes decolorises the stained organisms more than is desirable, and therefore Weigert devised the following method of dehydrating and clearing by aniline oil, which, though it may decolorise somewhat, does not do so to the same extent as alcohol. As much as possible of the water being removed, the section is placed in aniline oil; or if it has been cut in paraffin, some aniline oil is placed on the section, and the slide moved to and fro. The section is dehydrated and becomes clear. The process may be accelerated by heating gently. The preparation is then treated with a mixture of two parts of aniline oil and one part of xylol, and then with xylol alone, after which it is mounted in xylol balsam.

Sections stained for bacteria should always be *cleared*, at least finally, in xylol, for the same reason that xylol balsam is to be used for mounting films, viz. that it dissolves out aniline dyes less readily than such clearing reagents as clove oil, etc. Xylol, however, requires the previous de-

hydration to have been more complete than clove oil, which will clear a section readily when the dehydration has been only partially effected by, say, methylated spirit. If a little decolorisation of a section is still required before mounting, clove oil may be used to commence the clearing, the process being finished with xylol.

Another method of dehydration is that introduced by Unna. Here the section placed on the slide is dried in a current of air, or by gentle heating over the flame. This of course obviates all danger of decolorisation, but the tissue elements are shrunken and distorted, and the method therefore cannot be recommended.

We sometimes have to deal with bacteria which show a special tendency to be decolorised. This tendency can be obviated by adding a little of the stain to the alcohol, or aniline oil, employed in dehydration. In the latter case a little of the stain is rubbed down in the oil. The mixture is allowed to stand. After a little time a clear layer forms on the top with stain in solution, and this can be drawn off with a pipette.

The Formulæ of some of the more commonly used Stain Combinations.

1. *Löffler's Methylene-blue.*

Saturated solution of methylene-blue in alcohol, 30 c.c.
Solution of potassium hydrate in distilled water (1-10,000), 100 c.c.

(This dilute solution may be conveniently made by adding 1 c.c. of a 1 per cent solution to 99 c.c. of water.)

Sections may be stained in this mixture for from a quarter of an hour to several hours. They do not readily overstain. The tissue containing the bacteria is then decolorised with $\frac{1}{2}$-1 per cent acetic acid, till it is a pale blue-green. The section is washed in water, rapidly dehydrated with alcohol or aniline oil, cleared in xylol, and mounted.

The tissue may be contrast-stained with eosin. If this is desired, after decolorisation wash with water, place for a few seconds in 1 per cent solution of eosin in absolute alcohol, rapidly complete dehydration with pure absolute alcohol, and proceed as before.

Films may be stained with Löffler's blue by five minutes' exposure or longer in the cold. They do not usually require decolorisation, as the tissue elements are not overstained.

2. *Kühne's Methylene-blue.*

Methylene-blue, . . .	1.5 gr.
Absolute alcohol, . . .	10 c.c.
Carbolic acid solution (1-20), . .	100 c.c.

Stain and decolorise as with Löffler's blue, or decolorise with very weak hydrochloric acid (a few drops in a bowl of water).

3. *Carbol-Thionin-blue.*—Make up a stock solution consisting of 1 gram of thionin-blue dissolved in 100 c.c. carbolic acid solution (1-40). For use, dilute 1 volume with 3 of water and filter. Stain sections for five minutes or upwards. Wash very thoroughly with water, otherwise a deposit of crystals may occur in the subsequent stages. Decolorise with very weak acetic acid. A few drops of the acid added to a bowl of water is quite sufficient. Wash again thoroughly with water. Dehydrate with absolute alcohol or aniline oil. Thionin-blue stains more deeply than methylene-blue, and gives equally good differentiation. It is very suitable for staining typhoid and glanders bacilli in sections. Cover-glass preparations stained by this method do not usually require decolorisation.

4. *Gentian-violet in Aniline Oil Water.*—Two solutions have here to be made up. (*a*) Aniline oil water. Add about 5 c.c. aniline oil to 100 c.c. distilled water in a flask, and shake violently till as much as possible of the oil has dissolved. Filter and keep in a covered bottle to prevent access of light. (*b*) Make a saturated solution of gentian-violet in alcohol. When the stain is to be used, 1 part of (*b*) is added to 10 parts of (*a*), and the mixture filtered. The mixture should be made not more than twenty-four hours before use. Stain sections for a few minutes; then decolorise with methylated spirit. Sometimes it is advantageous to add to the methylated spirit a little hydrochloric acid (2-3 minims to 100 c.c.). This staining solution is not so much used by itself, as in Gram's method, which is presently to be described. Instead of aniline oil water, carbolic acid solution (1-20) may be used in the same way.

5. *Carbol-Fuchsin* (see p. 102).—This is a very powerful stain, and, when used in the undiluted condition, ½-1 minute's staining is usually sufficient. It is better, however, to dilute with three or four times its volume of water and stain for a few minutes. Methylated spirit with or without a few drops of acetic acid is the most convenient decolorising agent. Then dehydrate thoroughly, clear, and mount.

Various other staining combinations might be given, but the above are the best and most widely used. If the reader has thoroughly grasped the remarks made above on the general principles which underlie the staining of bacteria, he will be able to use any combination to which his attention may be directed. We may only add

here that different organisms take up and hold different stains with different degrees of intensity, and thus duration of staining and degree of decolorisation must be varied. It may be laid down as a general rule that, so long as organisms retain the stain, the greater the decolorisation of the tissues in which they lie, the clearer will be the results.

Gram's Method and its Modifications.—In the methods already described the tissues, and more especially the nuclei, usually retain some stain when decolorisation has reached the point to which it can safely go without the bacteria themselves being affected. In the method of Gram, now to be detailed, this does not occur, for the stain can here be removed completely from the ordinary tissues, and left only in the bacteria. All kinds of bacteria, however, are not stained by this method, or rather, in the stage of decolorisation some bacteria part with the stain as readily as, or even more readily than, the tissues. This fact is taken advantage of in certain circumstances to differentiate between different species of bacteria; and therefore in the systematic description of any species it is customary to state whether it is, or is not, stained by Gram's method. By this is meant, as will be understood from what has been said, whether the species retains the colour after the latter has been completely removed from the tissues. It has been said that, by Gram's method, the stain can generally be removed from the tissues. It must, however, be remarked that some tissue elements may retain the stain as firmly as any bacteria, *e.g.*, keratinised epithelium, calcified particles, the granules of mast cells, and sometimes altered red-blood corpuscles, etc.

In Gram's method the essential feature is the treating of the tissue, after staining, with a solution of iodine. This solution is spoken of as Gram's solution, and has the following composition:—

Iodine,	1 part.
Potassium iodide,	2 parts.
Distilled water,	300 parts.

The following is the method :—

1. Stain in aniline oil gentian-violet (*v. supra* No. 4) for about five minutes, and wash in water.
2. Treat the section or film with Gram's solution till its colour becomes a purplish black—generally about half a minute or a minute is sufficient for the action to take place.
3. Decolorise with absolute alcohol or methylated spirit till the colour has almost entirely disappeared, and the tissue appears only a very light violet.
4. Dehydrate completely, clear with xylol and mount. In the case of film preparations, the specimen is simply washed in water, dried and mounted.

Before (4) a contrast stain is often used (*vide infra*).

Gram's method, when carefully used, generally gives quite satisfactory results, but sometimes a precipitate of the gentian-violet is left in the tissues, and sometimes the specimen decolorises very slowly and the bacteria lose the stain in the process. We find that the result is more certain if in (1) the alcoholic gentian-violet be mixed with carbolic acid solution (1 : 20) instead of aniline oil water, and if in (3) clove oil be used in decolorising after the specimen has been sufficiently dehydrated with alcohol or methylated spirit. The clove oil decolorises rapidly, and must then be washed out with xylol, or, if a contrast stain is to be used, with alcohol. Nicolle has modified Gram's method by staining with carbol-gentian-violet as described, and, in (3), decolorising with a mixture of acetone one part and alcohol two parts. This also gives very good results. In Weigert's modification, aniline oil is used in (3) as the decolorising agent instead of alcohol. Other modifications have been introduced, of which only Kühne's need be mentioned.

Kühne's Modification of Gram's Method.

1. Stain for five minutes in a solution made up of equal parts of saturated alcoholic solution of crystal-violet ("krystall-violet") and 1 per cent solution of ammonium carbonate.
2. Wash in water.
3. Place for two to three minutes in Gram's iodine solution, or in the following modification by Kühne :—

Iodine	2 parts
Potassium iodide	4 parts
Distilled water	100 parts

For use, dilute with water to make a sherry-coloured solution.

4. Wash in water.

5. Decolorise in a saturated alcoholic solution of fluorescein (a saturated solution in methylated spirit does equally well).

6. Dehydrate, clear and mount.

Contrast Stains.—With all these methods it is often advantageous, after decolorisation, to counterstain the tissues with a dye different in colour from that retained by the bacteria.

Lithia carmine or alum carmine may be used for contrast-staining in Gram's method. The sections here are stained first with the contrast, and then treated by Gram's method.

In the case of the following stains the contrast-staining is not carried out till the tissues have been subjected to the bacterial stain and decolorised as far as possible.

Safranin.—Stock solution is a 1 per cent solution of safranin dissolved in equal parts of methylated spirit and water. For use, dilute one part with five of water, and stain for thirty seconds.

Bismarck-brown.—Stock solution—saturated solution in equal parts of alcohol and water. Stain for from two to three minutes.

Both safranin and Bismarck-brown are excellent nuclear stains, and in cases where Gram's method has been used, colour most of the organisms which are left unstained by the violet.

Eosin may be used as a 1-1000 watery solution, and applied for about a minute. It is a good ground stain, but does not bring out the nuclei.

After using a contrast stain, wash in water, dehydrate rapidly, clear and mount.

Stain for Tubercle and Leprosy Bacilli.—These bacilli cannot be well stained with a simple watery solution of a basic aniline dye. This fact can easily be tested by attempting to stain a film of a tubercle culture with such a solution. They require a powerful stain containing a mordant, and must be exposed to the stain for a long time, or the action of the latter may be aided by a short application of heat. When once stained, however, they resist decolorising with very powerful reagents. Any combination of gentian-violet

or fuchsin with aniline oil or carbolic acid or other mordant will stain the bacilli named, but the following methods are most commonly used :—

Ziehl-Neelsen Carbol-Fuchsin Stain.

Basic fuchsin	1 part
Absolute alcohol	10 parts
Solution of carbolic acid (1 : 20) .	100 parts

1. Place the specimen in this fluid, and having heated it till steam rises, allow it to remain there for five minutes, or allow it to remain in the cold stain for from twelve to twenty-four hours. (Films and paraffin sections are usually stained with hot stain, loose sections with cold ; in hot stain the latter shrink.)

2. Decolorise with 20 per cent solution of strong sulphuric acid, nitric acid, or hydrochloric acid, in water. In this the tissues become yellow.

3. Wash well with water. The tissues thus regain a faint pink tint. If the colour is distinctly red, the decolorisation is insufficient, and the specimen must be returned to the acid. As a matter of practice, it is best to remove the preparation from the acid every few seconds and wash in water, replacing the specimen in the acid and re-washing till the proper pale pink tint is obtained.

4. Contrast stain with a saturated watery solution of methylene-blue for half a minute, or with saturated Bismarck-brown for from two to three minutes.

5. Wash well with water. Dehydrate, clear, mount.

Fraenkel's modification of the Ziehl-Neelsen Stain.

Here the process is shortened by using a mixture containing both the decolorising agent and the contrast stain.

The sections or films are stained with the carbol-fuchsin as above described, and then placed in the following solution :—

Distilled water	50 parts
Absolute alcohol	30 parts
Nitric acid	20 parts
Methylene-blue in crystals to saturation.	

They are treated with this till the red colour has quite disappeared and been replaced by blue.

Leprosy bacilli are stained in the same way, but are rather more easily decolorised than tubercle bacilli, and it is better to use only 5 per cent sulphuric acid in decolorising.

In the case of specimens stained either by the original Ziehl-Neelsen method, or by Fraenkel's modification, the tubercle or leprosy bacilli ought to be bright-red, and the tissue blue or brown, according to the contrast stain used. Other bacteria which may be present are also coloured with the contrast stain.

Staining of Spores.—If bacilli containing spores are stained with a watery solution of a basic aniline dye the spores remain unstained. The spores either take up the stain less readily than the protoplasm of the bacilli or they have a resisting envelope which prevents the stain penetrating to the protoplasm. Like the tubercle bacilli, when once stained they retain the colour with considerable tenacity. The following is the method for staining spores :—

1. Stain cover-glass films as for tubercle bacilli.
2. Decolorise with 1 per cent sulphuric acid in water or with methylated spirit. This removes the stain from the bacilli.
3. Wash in water.
4. Stain with saturated watery methylene-blue for half a minute.
5. Wash in water, dry, and mount in balsam.

The result is that the spores are stained red, the protoplasm of the bacilli blue.

The spores of some organisms lose the stain more readily than those of others, and for some, methylated spirit is a sufficiently strong decolorising agent for use. If sulphuric acid stronger than 1 per cent is used the spores of many bacilli are readily decolorised.

Möller recommends that before being stained the films should be placed in chloroform for 2 minutes, and then in a 5 per cent solution of chromic acid for $\frac{1}{2}$-2 minutes. This procedure has an advantage in some cases, though in many it is unnecessary.

The Staining of Flagella.—The staining of the flagella of bacteria is the most difficult of all bacteriological procedures, and it requires considerable practice to ensure that good results shall be obtained. Many methods have

been introduced, but practically only two need be described here as they are the best at present known. One is the original method of Löffler. The other is that of van Ermengem, and it has lately attained considerable popularity.

In all the methods of staining flagella, young cultures on agar should be used, say a culture incubated for twelve to eighteen hours at 37° C. A very small portion of the growth is taken on the point of a platinum needle and carefully mixed in a little water in a watch glass; the amount should be such as to produce scarcely any turbidity in the water. A film is then made by placing a drop on a clean cover-glass and carefully spreading it out with the needle. It is allowed to dry in the air and then passed twice or thrice through a flame, care being taken not to over-heat it. The cover-glasses used should always be cleaned in the mixture of sulphuric acid and potassium bichromate described on page 84.

1. *Löffler's Method for Staining Flagella.*

Two solutions must be made up. Löffler gives the following directions for their preparation :—

A. *The Mordant.*—To 10 c.c. of a 20 per cent solution of tannin in water add as many drops of a saturated solution of ferrous sulphate in water as will give the whole fluid a dark-violet tint. To this add 3-4 c.c. of a solution made by boiling 1 gram of logwood with 8 c.c. of water (after boiling, filter and make up to 9 c.c. to compensate for evaporation). The mixture of the tannin solution with the logwood solution appears of a dirty dark-violet colour. If too much logwood is added particles are precipitated which make the fluid useless as a mordant. It is preferable to make up this mordant fresh on each occasion of its use. After standing for a few days it becomes almost black. It still, however, may be used, although it may now have a slight scum on the surface. The addition of 4-5 c.c. of 1-20 carbolic acid solution makes the fluid more permanent without impairing its properties.

B. *The Stain.*—To 100 c.c. of a filtered saturated solution of aniline oil in water add 1 c.c. of a 1 per cent solution of sodium hydrate. The aniline water is ordinarily neutral. The addition of the soda renders it slightly alkaline. To this solution add 4-5 grm. of solid methylene-violet, methylene-blue or fuchsin, and shake well. When a preparation is to be stained, filter a few drops on to the cover-glass.

Make a film as above described, and holding the cover-glass in a pair of forceps, pour on as much of the mordant A as the cover-glass will hold. Heat it carefully above a flame till steam begins to rise and then move the preparation gently in and out of the hot-air column over the flame for about a minute. Wash well in distilled water till every trace of mordant appears to be gone. If necessary, wash with absolute alcohol till only the film itself appears tinted violet with the mordant. Filter a few drops of stain B on to the cover, again heat till steam rises and leave in the warm stain for one minute. Wash well in distilled water, dry, and mount in xylol balsam.

2. *Van Ermengem's Method for Staining Flagella.*

The films are prepared as above described. Three solutions are here necessary :—

Solution A. (*Bain fixateur*)—

Osmic acid, 2 per cent solution . . .	1 part
Tannin, 10-25 per cent solution . . .	2 parts

Place the films in this for one hour at room temperature, or heat over a flame till steam rises, and keep in the hot stain for five minutes. Wash with distilled water, then with absolute alcohol for three to four minutes, and again in distilled water, and treat with

Solution B. (*Bain sensibilisateur*)—

.5 per cent solution of nitrate of silver in distilled water. Allow films to be in this a few seconds. Then without washing transfer to

Solution C. (*Bain reducteur et reinforçateur*)—

Gallic acid	5 gr.
Tannin	3 gr.
Fused potassium acetate	10 gr.
Distilled water	350 c.c.

Keep in this for a few seconds. Then treat again with Solution B till the preparation begins to turn black. Wash, dry, and mount.

It is better, as Mervyn Gordon recommends, to leave the specimen in B for two minutes and then to transfer to C for one and a half to two minutes, and not to transfer again to B. It will also be found an advantage to use a fresh supply of C for each preparation, a small

quantity being sufficient. The beginner will find the typhoid bacillus or the B. coli communis very suitable organisms to stain by this method.

General Bacteriological Diagnosis.

Under this heading we have to consider the general routine which is to be observed by the bacteriologist when any material is submitted to him for examination. The object of such examination may be to determine whether any organisms are present, and if so, what organisms; or the bacteriologist may simply be asked whether a particular organism is or is not present. In any case his inquiry must consist (1) of a microscopic examination of the material submitted; (2) of an attempt to isolate the organisms present; and (3) of the identification of the organisms isolated. We must, however, before considering these points look at a matter often neglected by those who seek a bacteriological opinion, viz.: the *proper methods of obtaining and transferring to the bacteriologist the material which he is to be asked to examine.* The general principles here are (1) that every precaution must be adopted to prevent the material from being contaminated with extraneous organisms; (2) that nothing be done which may kill any organisms which may be proper to the inquiry; and (3) that the bacteriologist obtain the material as soon as possible after it has been removed from its natural surroundings.

The sources of materials to be examined, even in pathological bacteriology alone, are of course so varied that we can but mention a few examples. It is, for instance, often necessary to examine the contents of an abscess. Here the skin must be carefully purified by the usual surgical methods; the knife used for the incision is preferably to be sterilised by boiling, the first part of the pus which escapes allowed to flow away (as it might be spoiled by containing some of the antiseptics used in the purification) and a little of what subsequently escapes

allowed to flow into a sterile test-tube. If test-tubes sterilised in a laboratory are not at hand, an ordinary test-tube may be a quarter filled with water, which is then boiled well over a spirit-lamp. The tube is then emptied and plugged with a plug of cotton wool, the outside of which has been singed in a flame. Small stoppered bottles may be boiled and used in the same way. A discharge to be examined may be so small in quantity as to make the procedure described impracticable. It may be caught on a piece of sterile plain gauze, or of plain absorbent wool which is then placed in a sterile vessel. Wool or gauze used for this purpose, or for swobbing out, say the throat, to obtain shreds of suspicious matter, must have no antiseptic impregnated in it, as the latter may kill the bacteria present and make culture experiments impossible.

Fluids from the body cavities, urine, etc., may be secured with sterile pipettes. To make one of these, take nine inches of ordinary quill glass-tubing, draw out one end to a capillary diameter, and place a little plug of cotton wool in the other end. Insert this tube through the cotton plug of an ordinary test-tube and sterilise by heat. To use it, remove test-tube plug with the quill tube in its centre, suck up some of the fluid into the latter, and replace in its former position in the test-tube (Fig. 37). Another method very convenient for transport is to make two constrictions on the glass tube at suitable distances, according to the amount of fluid to be taken. The fluid is then drawn up into the part between the constrictions, but so as not to fill it completely. The tube is then broken through at both constrictions and the thin ends are sealed by heating in a flame.

FIG. 37.—Test-tube and pipette arranged for obtaining fluids containing bacteria.

Solid organs to be examined should, if possible, be

obtained whole. They may be treated in one of two ways. 1. The surface over one part about an inch broad is seared with a cautery heated to dull red heat. All superficial organisms are thus killed. An incision is made in this seared zone with a sterile scalpel, and small quantities of the juice are removed by a platinum loop to make cover-glass preparations and plate or smear cultures. 2. An alternative method is as follows :—The surface is sterilised by soaking it well with 1 to 1000 corrosive sublimate for half an hour. It is then dried, and the capsule of the organ is cut through with a sterile knife, the incision being further deepened by tearing. In this way a perfectly uncontaminated surface is obtained. Hints are often obtained from the clinical history of the case as to what the procedure ought to be in examination. Thus, as a matter of practice, cultures of tubercle and often of glanders bacilli can be easily obtained only by inoculation experiments. Typhoid bacilli need hardly be looked for in the fæces after the first ten days of the disease, and so on.

Routine Procedure in Bacteriological Examination of Material.—In the case of a discharge regarding which nothing is known the following procedure should be adopted :—(1) Several cover-glass preparations should be made. One ought to be stained with saturated watery methylene-blue, one with a stain containing a mordant such as Ziehl-Neelsen carbol-fuchsin, one by Gram's method. (2) (*a*) Gelatine plates should be made and kept at room temperature, (*b*) a series of agar plates or successive strokes on agar tubes (p. 62) should be made and incubated at 37° C. Method (*b*) of course gives results more quickly. If microscopic investigation reveals the presence of bacteria, it is well to keep the material in a cool place till next day when if no growth has appeared in the incubated agar some other culture methods (*e.g.*, blood serum or agar smeared with blood) may be applied. If growth has taken place, say in the agar plates, one with about 200 or fewer colonies should be made the chief basis for research. In such a plate the first question to be cleared up is: Do all the

colonies present consist of the same bacterium? The final settlement of this question depends on microscopic examination, but it is seldom necessary to examine all the colonies in this way; for particular bacteria when growing in mass in a colony frequently present characteristic appearances, which may be recognised even by the naked eye or at least by a $\frac{1}{2}$ inch or 1 inch objective. The shape of the colony, its size, the appearance of the margin, the graining of the substance, its colour, etc. are all to be noted. One precaution is necessary, viz. it must be noted whether the colony is on the surface of the medium or in its substance, as the same bacterium may exhibit differences in its colonies according to their position. The arrangement of the bacteria in a surface colony may be still more minutely studied by means of *impression preparations*. A cover-glass is carefully cleaned and sterilised by passing quickly several times through a Bunsen flame. It is then placed on the surface of the medium and gently pressed down on the colony. The edge is then raised by a sterile needle, it is seized with forceps, dried high over the flame, and treated as an ordinary cover-glass preparation. In this way very characteristic appearances may sometimes be noted and preserved, as in the case of the anthrax bacillus. The colonies on a plate having been classified, a microscopic examination of each group must be made by means of cover-glass preparations, and tubes of gelatine and agar are inoculated from each representative colony. Each of the colonies used must be marked for future reference, preferably by drawing a circle round it on the under surface of the plate or capsule with one of Faber's pencils for marking on glass, a number or letter being added for easy reference.

The general lines along which observation is to be made in the case of a particular bacterium may be indicated as follows:—

1. *Microscopic appearances.*—Note (1) the form, (2) the size, (3) the appearance of the protoplasmic contents, especially as regards uniformity or irregularity of staining. Has it a capsule? (4) the method of grouping, (5) the

staining reactions. Does the bacterium stain with simple watery solutions? Does it require the use of stains containing mordants? How does it behave towards Gram's method? It is important to investigate the first four points both when the organism is in the fluids or tissues of the body and when growing in artificial media, as slight variations occur. It must also be borne in mind that slight variations are observed according to the kind and consistence of the medium in which the organism is growing. (6) Is it motile and has it flagella? If so, how are they arranged? (7) Does it form spores, and if so, under what conditions as to temperature, etc.?

2. *Growth characteristics.*—Here the most important points on which information is to be asked are, What are the characters of growth and what are the relations of growth (1) to temperature (2) to oxygen? These can be answered from some of the following experiments:—

A. Growth on gelatine. (1) Stab culture. Note (*a*) rate of growth; (*b*) form of growth, (*α*) on surface, (*β*) in substance; (*c*) presence or absence of liquefaction; (*d*) colour; (*e*) presence or absence of gas formation and of characteristic smell; (*f*) relation to reaction of medium. (2) Streak culture. (3) Shake culture. (4) Plate cultures. Note appearances of colonies (*a*) superficial, (*b*) deep. (5) Growth in fluid gelatine at 37° C.

B. Growth on agar at 37° C. (1) Stab. (2) Streak. Also on glycerine agar, blood agar, etc. Appearances of colonies in agar plates.

C. Growth in bouillon, (*a*) character of growth, (*b*) smell, (*c*) reaction.

D. Growth on special media. (1) Solidified blood serum. (2) Potatoes. (3) Lactose and other sugar media. Does fermentation occur and is gas formed? (4) Milk. Is it curdled or turned sour? (5) Litmus media. Note changes in colour. (6) Peptone solution. Is indol formed?

E. What is viability of organism on artificial media?

3. *Results of inoculation experiments on animals.*

By attention to such points as these a considerable

knowledge is attained regarding the bacterium, which will lead to its identification. In the case of many well-known organisms, however, a few of the above points taken together will often be sufficient for the recognition of the species, and experience teaches what are the essential points as regards any individual organism. In the course of the systematic description of the pathogenic organisms, it will be found that all the above points will be referred to, though not in every case.

Inoculation of Animals.[1]

The animals generally chosen for inoculation are the mouse, the rat, the guinea-pig, the rabbit, and the pigeon. Great caution must be shown in drawing conclusions from isolated experiments on rabbits, as these animals often manifest exceptional symptoms, and are very easily killed. Dogs are, as a rule, rather insusceptible to microbic disease, and the larger animals are too expensive for ordinary laboratory purposes. In the case of the mouse and rat the variety must be carefully noted, as there are differences in susceptibility between the wild and tame varieties and the white and brown varieties of the latter. In the case of the wild varieties, these must be kept in the laboratory for a week or two before use, as in captivity they are apt to die from very slight causes, and, further, each individual should be kept in a separate cage, as they show great tendencies to cannibalism. Of all the ordinary animals the most susceptible to microbic disease is the guinea-pig. Practically all inoculations are performed by means of the hypodermic syringe. The best variety is made on the ordinary model with metal mountings, asbestos washers, and preferably furnished with platinum iridium needles. Before use the needle is mounted on the piston and sterilised by boiling for five minutes. The materials used for inoculation are cultures, animal exudations, or the juice of organs. If the

[1] Experiments on animals, of course, cannot be performed in this country without a license granted by the Home Secretary.

bacteria already exist in a fluid there is no difficulty. The needle is most conveniently filled out of a shallow conical test glass which ought previously to have been covered with a cover of filter paper and sterilised. If an inoculation is to be made from organisms growing on the surface of a solid medium, either a little ought to be scraped off and shaken up in sterile distilled water or .75 per cent salt solution to make an emulsion, or a little sterile fluid is poured on the growth and the latter scraped off into it. This fluid is then filtered into the test glass through a plug of sterile glass wool. This is easily effected by taking a piece of $\frac{5}{8}$ in. glass-tubing 3 in. long, drawing one end out to a fairly narrow point, plugging the tube with glass wool above the point where the narrowing commences, and sterilising by heat. By filtering an emulsion through such a pipette flocculi which might block the needle are removed. If a solid organ or an old culture is used for inoculation it ought to be rubbed up in a sterile porcelain or metal crucible with a little sterile distilled water, by means of a sterile glass rod, and the emulsion filtered as in the last case.

The methods of inoculation generally used are: (1) by scarification of the skin; (2) by subcutaneous injection; (3) by intraperitoneal injection; (4) by intravenous injection; (5) by injections into special regions, such as the anterior chamber of the eye, the substance of the lung, etc. Of these (2) and (3) are most frequently used. When an anæsthetic is to be administered, this is conveniently done by placing the animal, along with a piece of cotton wool or sponge soaked in chloroform, under a bell-jar or inverted glass beaker of suitable size.

1. *Scarification.*—A few parallel scratches are made in the skin of the abdomen previously cleansed, just sufficiently deep to draw blood, and the infective material is rubbed in with a platinum eyelet. The disadvantage of this method is that the inoculation is easily contaminated. The method is only occasionally used.

2. *Subcutaneous Injection.*—A hypodermic syringe is filled with the substance to be inoculated. The part chosen

for inoculation is either near the root of the tail, or between the scapulæ, the advantage being that the animal cannot suck the point of inoculation in such situations. The hair is cut off the part, and the skin purified with 1 to 1000 corrosive sublimate. The skin is then pinched up, and the needle being inserted the requisite dose is administered. The wound is then sealed with a little collodion.

3. *Intraperitoneal Injection.*—This is best performed by means of a special form of needle. The needle is curved, and has its opening not at the point, but in the side in the middle of the arch (Fig. 38). The hair over the lower part of the abdomen is cut, and the skin purified with an antiseptic. The whole thickness of the abdominal walls is then pinched up by an assistant, between the forefingers and thumbs of the two hands. The needle is then plunged through the fold thus formed. The result is that the hole in the side of the needle is within the abdominal cavity, and the inoculation can thus be made. Intraperitoneal inoculation can also be practised with an ordinary needle. The mode of procedure is similar, but after the needle is plunged through the abdominal fold, it is partially withdrawn till the point is felt to be free in the peritoneal cavity when the injection is made. There is little risk of injuring the intestines by either method.

FIG. 38.—Hollow needle with lateral aperture (at *a*) for intraperitoneal inoculations.

4. *Intravenous Injection.*—The vein most usually chosen is one of the auricular veins. The part has the hair removed, the skin is purified, and the vein made prominent by pressing on it between the point of inoculation and the heart. The needle is then plunged into the vein and the fluid injected. That it has perforated the vessel will be shown by the escape of a little blood; and that the injection has taken place into the lumen of the vessel will be known by the absence of the small swelling which occurs in subcutaneous injections. If preferred, the vein may be first

laid bare by snipping the skin over it. The needle is then introduced.

5. *Inoculation into the Anterior Chamber of the Eye.*—Local anæsthesia is established by applying a few drops of 2 per cent solution of hydrochlorate of cocaine. The eye is fixed by pinching up the orbital conjunctiva with a pair of fine forceps, and the edge of the cornea being perforated by the hypodermic needle, the injection is easily accomplished.

Sometimes inoculations are made by planting small pieces of pathological tissues in the subcutaneous tissue. This is especially used in the case of glanders and tubercle. The skin over the back is purified, and the hair cut. A small incision is made with a sterile knife, and the skin being separated from the subjacent tissues by means of the ends of a blunt pair of forceps, a little pocket is formed into which a piece of the suspected tissue is inserted. The wound is then closed with a suture, and collodion is applied. In the case of guinea-pigs, the back ought not to be the site of inoculation, as the skin is extremely thick in that region.

Injections are sometimes made into other parts of the body, *e.g.*, the pleuræ and the cranium. It is unnecessary to describe these, as the application of the general principles employed above, together with those of modern aseptic surgery, will sufficiently guide the investigator to the technique which is requisite.

After inoculation, the animals ought to be kept in comfortable cages, which must be capable subsequently of easy and thorough disinfection. For this purpose galvanised iron wire cages are the best. They can easily be sterilised by boiling them in the large fish kettle which it is useful to have in a bacteriological laboratory for such a purpose. The general condition of the animal is to be observed, how far it differs from the normal, whether there is increased rapidity of breathing, etc. The temperature is usually to be taken. This is generally done *per rectum*. To do it, the thermometer (the ordinary 5 min. clinical variety) is

smeared with vaseline, and the bulb inserted just within the sphincter, where it is allowed to remain for a minute; it is then pushed well into the rectum for five minutes. If this precaution be not adopted, a reflex contraction of the vessels may take place, which is likely to vitiate the result by giving too low a reading.

Autopsies on Animals dead or killed after Inoculation.—These should be made as soon as possible after death. It is necessary to have some shallow troughs, constructed either of metal or of wood covered with metal, conveniently with sheet lead, and having a perforation at each corner to admit a tape or strong cord. The animal is tightly stretched out in the trough and tied in position. The size of the trough will, therefore, have to vary with the size of the outstretched body of the animal to be examined. In certain cases it is well to soak the surface of the animal in carbolic acid solution (1 to 20), or in corrosive sublimate (1 to 1000) before it is tied out. This not only to a certain extent disinfects the skin but, what is more important, prevents hairs which might be infected with pathogenic products from getting into the air of the laboratory. The instruments necessary are scalpels (preferably with metal handles), dissecting forceps, and scissors. They are to be sterilised by boiling for five minutes. This is conveniently done in one of the small portable sterilisers used by surgeons. Two sets at least ought to be used in an autopsy, and they may be placed, after boiling, on a sterile glass plate covered by a bell jar. It is also necessary to have a medium-sized hatchet-shaped cautery, or other similar piece of metal. It is well to have prepared a few freshly-drawn-out capillary tubes stored in a sterile cylindrical glass vessel, and also some larger sterile glass pipettes. The abdomen of the animal has the hair removed. If some of the peritoneal fluid is wanted, a band should be cauterised down the linea alba from the sternum to the pubes, and another at right angles to the upper end of this; an incision should be made in the middle of these bands, and the abdominal walls thrown to each side. One or more

capillary tubes should then be filled from the fluid collected in the flanks, the fluid being allowed to run up the tube and the point sealed off; or a larger quantity, if desired, is taken in a sterile pipette. If peritoneal fluid be not wanted, then an incision may be made from the episternum to the pubes, and the thorax and abdomen opened in the usual way. The organs ought to be removed with another set of instruments, and it is convenient to place them pending examination in deep Petri's capsules (sterile). It is generally advisable to make cultures and film preparations from the heart's blood. To do this, open the pericardium, sear the front of the right ventricle with a cautery, make an incision in the middle of the part seared, and remove some of the blood with a capillary tube for future examination, or, introducing a platinum eyelet, inoculate tubes and make cover-glass preparations at once. To examine any organ, sear the surface with cautery, cut into it, and inoculate tubes and make film preparations with a platinum loop. Place pieces of the organs in some preservative fluid for microscopic examination. The organs ought not to be touched with the fingers. When the *post mortem* is concluded the body should have corrosive sublimate or carbolic acid solution poured over it, and be forthwith burned. The dissecting trough and all the instruments ought to be boiled for half an hour. The amount of precaution to be taken will, of course, depend on the character of the bacterium under investigation, but as a general rule every care should be used.

CHAPTER IV.

NON-PATHOGENIC MICRO-ORGANISMS—FUNGI.

It is quite outside the scope of the present volume to describe any bacteria other than those giving rise to disease processes. In the course of his work the bacteriologist frequently comes across ordinary saprophytic organisms. These may occur in diseased organs in which putrefaction has already begun to take place, and they may therefore appear in cultures made from such organs. Their source in cultures may, further, be by contamination from the air, or from the use of insufficiently sterilised vessels or instruments. The positive characters of the pathogenic bacteria will be given, and from these other bacteria must be distinguished by the application of the methods of diagnosis already detailed, or by the special methods still to be described. There occur, however, from time to time as contaminations of bacterial cultures, organisms of a more complicated structure than the bacteria, namely fungi, and therefore we shall describe a few of the typical forms of these.

The fungi have probably descended from the algæ, or both have had a common ancestor. This is shown by the close resemblances in structure and development which the two groups present to each other. The chief differences centre round the degeneration of structure which the adoption of parasitism entails on the fungi. In the algæ, reproduction takes place in both sexual and non-sexual ways. In the former case, certain cells called gametes are set apart, and by

the union of two of these—the embryonic male and female elements—a new cell called a zygospore is formed which after a period of rest grows into a new individual. Sometimes there is a more definite male element, the antheridium, and a female element, the oosphere, and the coalescence of these forms an oospore which subsequently behaves like a zygospore. In the non-sexual reproduction there are formed certain cells called brood-cells or gonidia the protoplasm of which, without being reinforced from that of another cell, proceeds to break up into the elements of new individuals often called swarm-spores. Both forms of reproduction are usually manifested by each species. The degradation of the fungi consists in the gradual loss of the faculty of sexual reproduction, so that, in the lower species of the group, it does not appear at all and only gonidium formation can be traced. We shall now describe a few of the typical forms of these lower fungi which are often met with in bacteriological work.

Mucorinæ : Mucor Mucedo.—This form occurs especially in the putrefaction of horse dung and also in other putrefactions. To the naked eye it appears as a white or brownish-white mass of fine filaments, from which, here and there, rise special filaments often several inches long, having at their terminations spherical brown swellings, the reproductive elements. Microscopically, the plant consists of branching non-septate filaments. Such a structure is called a mycelium. The non-sexual is the commonest form of reproduction (*vide* Fig. 39 A4). One of the filaments grows out, at its termination a septum forms, and a globular swelling (the brood-cell) appears. This brood-cell possesses a definite membrane. Within it from the septum, grows a club-shaped mass of protoplasm called the columella, to which are attached the swarm-spores formed from the breaking up of the rest of the protoplasm. When ripe the brood-cell bursts, the brown swarm-spores are cast off, and from each a new individual arises. Under certain circumstances sexual reproduction occurs (*vide* Fig. 39 A1–3). Two filaments approach each other, and a small piece of

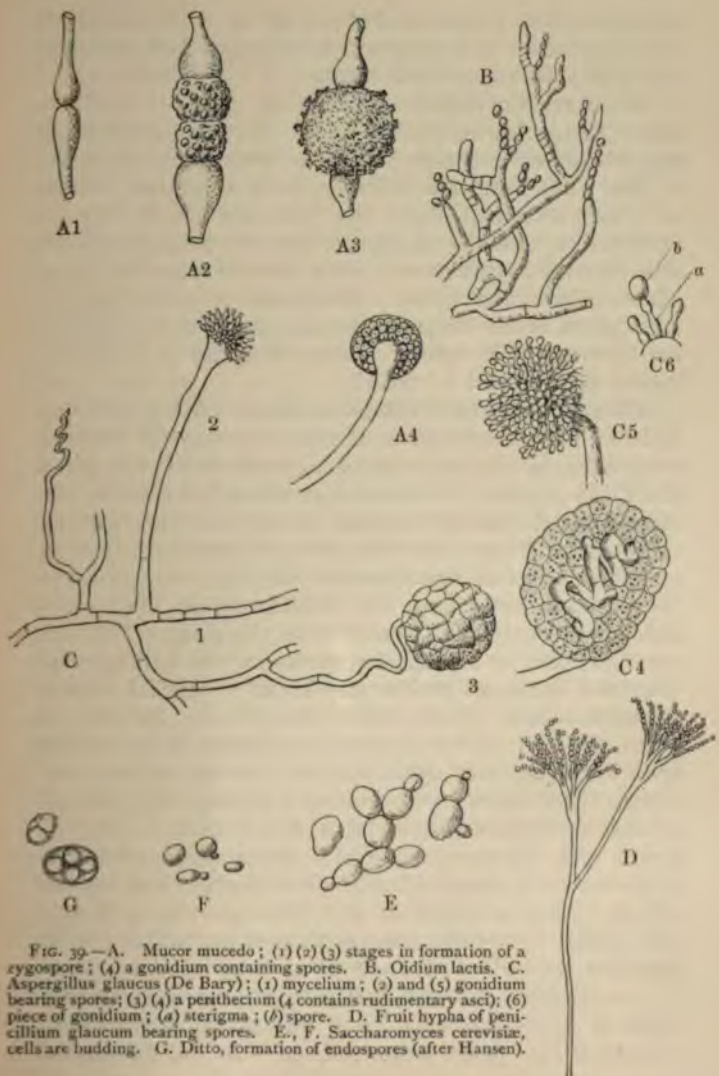

FIG. 39.—A. Mucor mucedo; (1) (2) (3) stages in formation of a zygospore; (4) a gonidium containing spores. B. Oidium lactis. C. Aspergillus glaucus (De Bary); (1) mycelium; (2) and (5) gonidium bearing spores; (3) (4) a perithecium (4 contains rudimentary asci); (6) piece of gonidium; (*a*) sterigma; (*b*) spore. D. Fruit hypha of penicillium glaucum bearing spores. E., F. Saccharomyces cerevisiæ, cells are budding. G. Ditto, formation of endospores (after Hansen).

the protoplasm of each being cut off by a septum, these parts coalesce. A zygospore is thus formed from which a new filamentous individual arises.

Ascomycetæ: Oidium Lactis (Fig. 39 B).—This is a common organism in sour milk and sour bread. It can easily be cultivated on gelatine where the colonies appear to consist of fine white filaments radiating from a centre. Microscopically here and there the filaments (which may be branched) are broken up, especially at the ends, into short rod-shaped or oval segments often referred to as the oidia. These behave like spores. Non-sexual reproduction also takes place by the formation, within certain special cells in the filament, of a definite number of spores to which the special name of asci is applied.

Perisporiaceæ: (1) **Aspergillus Niger** (*vide* Fig. 39 C).—This, with other varieties of the same group is of frequent occurrence, in especially vegetable putrefactions. It grows readily in gelatine. It consists, to the naked eye, like the other fungi described, of a mass of felted filaments which microscopically are seen to form a septate branching mycelium. Sexual reproduction does not take place, but two forms of non-sexual reproduction occur, the variety depending largely on the nutrition of the plant. The less common form is effected by means of the formation of structures known as perithecia. From a mycelial branch a filament arises. At the end of this a swelling occurs, into which the end of the filament penetrates and, twisting upon itself, becomes detached and lies free in the protoplasm. This twisted part ultimately divides into a limited number (not more than eight) of oval bodies, the asci or spores, and, the surrounding protoplasm disappearing, the latter lie free in the membrane. This ruptures and the asci escape. After a period of rest these develop into new individuals. The commonest method of reproduction is by gonidium formation. Here a filament grows out, and at its termination a club-shaped swelling is formed on which a series of flask-shaped masses of protoplasm called sterigmata (*vide* Fig. 39 C6) are perched. At the free end of

each of these, an oval body, the spore is formed, and this becoming free, can give rise to a new individual.

(2) **Penicillium Glaucum.**—This is perhaps the most common of all the fungi met with in bacteriological work. It is the common green cheese mould, and its spores are practically omnipresent. The mycelium is like that of the aspergillus. Perithecium formation takes place, but the commonest mode of reproduction is by gonidia (*vide* Fig. 39 D). A filament (called a fruit hypha) grows out, and at its end breaks up into a number of finger-like branches. On the point of each of these a flask-shaped sterigma is developed. On the end of this a row of oval spores appears. These break off, and can give rise to new individuals.

Yeasts and Torulæ: Saccharomyces, Torula, Mycoderma.—These are of the greatest importance, of course, in brewing and baking. They only concern us as being of not uncommon occurrence in the air. They consist of round or oval cells usually many times larger than bacteria. They often reproduce themselves by budding (*vide* Fig. 39 E, F), a portion of the protoplasm protruding, and finally being cut off to form a new individual. Endogenous spore formation also occurs (*vide* Fig. 39 G). Many of the torulæ, when growing in colonies, are brilliantly coloured. What their true morphological relationships are it is difficult to say, but they present many analogies to the oidia of such forms as oidium lactis.

A knowledge of the above type forms will enable the student to recognise the more common fungi as such, when they present themselves to him. For further information on this group he is referred to De Bary's book on *The Fungi*. Certain fungi closely related to the above are pathogenic agents. Some aspergilli have been found to grow in the animal tissues and to produce death, and to the fungi also belong the saprolegnia ferax (the cause of salmon disease), the tinea tonsurans, and the Achorion Schoenleinii.

CHAPTER V.

RELATIONS OF BACTERIA TO DISEASE—THE PRODUCTION OF TOXINES BY BACTERIA.

Introductory.—It has already been stated that a strict division of micro-organisms into *saprophytes* and true *parasites* cannot be made. No doubt there are organisms such as the bacillus of leprosy and the spirillum of relapsing fever which as yet have not been cultivated outside the animal body, and others, such as the gonococcus, which are in natural conditions always parasites associated with disease. But these latter can lead a saprophytic existence in specially prepared conditions, and there are many of the disease-producing organisms, such as the organisms of typhoid and cholera, which can flourish readily outside the body, even in ordinary conditions. The conditions of growth are however of very great importance in the study of the methods of infection in the various diseases, though they do not form the basis of a scientific division.

A similar statement applies to the terms *pathogenic* and *saprophytic*, and even to the terms *pathogenic* and *non-pathogenic*. By the term pathogenic is meant the power which an organism has of producing morbid changes or effects in the animal body, either under natural conditions or in conditions artificially arranged as in direct experiment. Now we know of no organisms which will in all circumstances produce disease in all animals, and, on the other hand, many bacteria described as harmless saprophytes

will produce pathological changes if introduced in sufficient quantity. When, therefore, we speak of a pathogenic organism, the term is merely a relative one, and indicates that in certain circumstances the organism will produce disease, though in the science of human pathology it is often used for convenience as implying that the organism produces disease in man in natural conditions.

Modifying Conditions.—In studying the pathogenic effects in any instance, both the micro-organisms and the animal affected must be considered, and not only the species of each, but also its exact condition at the time of infection. In other words, the resulting disease is the product of the sum total of the characters of the infecting agent, on the one hand, and of the subject of infection, on the other. We may, therefore, state some of the chief circumstances which modify each of these two factors involved and, consequently, the diseased condition produced.

1. *The Infecting Agent.*—In the case of a particular species of bacterium its effect will depend chiefly upon (*a*) its virulence, and (*b*) the number introduced into the body. To these may be added (*c*) the path of infection.

The *virulence*, *i.e.* the power of multiplying in the body and producing disease, of micro-organisms varies greatly in different conditions, and the methods by which it can be diminished or increased will be afterwards described (*vide* Chapter XIX.). Here it may simply be stated that widely different effects may be produced by altering the virulence. For example, a streptococcus which produces merely a local inflammation or suppuration, may produce a rapidly fatal septicæmia on its virulence being exalted. The virulence also has a relation to the animal employed, as sometimes on being increased for one species of animal it is diminished for another. For example, streptococci, on being inoculated in series through a number of mice, acquire increased virulence for these animals, but become less virulent for rabbits. (Knorr.)

The *number* of the organisms introduced or the dose of the infecting agent is another point of importance. The

healthy tissues can usually resist a certain number of pathogenic organisms of given virulence, and it is only in a few instances that one or two organisms introduced will produce a fatal disease, *e.g.*, the case of anthrax in white mice. The healthy peritoneum of a rabbit can resist and destroy a considerable number of pyogenic micrococci without becoming inflamed, but if a larger dose be introduced, inflammation or suppuration will follow. Again, a certain quantity of a particular organism injected subcutaneously may produce only a local inflammatory change, but in the case of a larger dose the organisms may gain entrance to the blood stream and produce septicæmia. There is in the case of many organisms a minimum lethal dose for a particular animal, which can be determined by experiment only.

The path of infection may alter the result, serious effects in many instances following especially a direct entrance into the blood stream. Staphylococci injected subcutaneously in a rabbit may produce only a local abscess, but if injected in the same quantity into the blood stream, multiple abscesses in certain organs and death may follow. In the former case the organisms in the subcutaneous tissue produce around them an inflammatory or suppurative area to which they are practically confined. The nature and significance of this local inflammatory change will not be discussed here, but it may be stated that in many cases it is followed by the destruction of the organisms. In some other cases, however, the organisms are very rapidly destroyed in the blood stream, and Klemperer has found that in the dog, subcutaneous injection of the pneumococcus produces death more readily than intravenous injection.

2. *The Subject of Infection.* — Susceptibility and, in inverse ratio, resistance to a particular microbe vary much in different species and in different varieties of the same species. White rats are practically immune against anthrax infection, guinea-pigs are very susceptible to it; field mice are amongst the most susceptible animals to glanders, while

white mice enjoy a high degree of immunity, and so on. Then there are diseases, of which leprosy is a good example, which appear to be peculiar to the human subject and have not yet been transmitted to animals. And further, there are others, such as cholera and typhoid, which do not naturally affect animals, and the typical lesions of which cannot be experimentally reproduced in them, or appear only imperfectly, though pathogenic effects follow inoculation with the organisms. In the case of the human subject, differences in susceptibility to a certain disease are found amongst different races and also amongst individuals of the same race, as is well seen in the case of tubercle and other diseases. Age also plays an important part, young subjects being more liable to certain diseases, *e.g.*, to diphtheria. Further, at different periods of life certain parts of the body are more susceptible, for example, in early life, the bones and joints to tubercular and acute suppurative affections.

The natural resistance or immunity possessed by an animal may be artificially lowered by certain methods, of which the following well-recognised examples may be given. Frogs, which are naturally immune to anthrax, can be rendered susceptible to infection by being kept at a temperature of about 35° C. Rats naturally immune can be rendered susceptible to glanders by being fed with phloridzin, which produces a sort of diabetes, a large amount of sugar being excreted in the urine. (Leo.) Guinea-pigs may resist subcutaneous injection of a certain dose of the typhoid bacillus, but if at the same time a sterilised culture of the bacillus coli be injected into the peritoneum, they quickly die of a general infection. Also a local susceptibility may be produced by injuring or diminishing the vitality of a part. If, for example, previous to an intravenous injection of staphylococci, the aortic cusps of a rabbit be injured, the organisms may settle there and set up an ulcerative endocarditis, or if a bone be injured, they may produce suppuration at the part, whereas in ordinary circumstances these lesions would not take

place. The action of one species of bacterium is also often aided by the simultaneous presence of other species. In this case the latter may act simply as additional irritants which lessen the vitality of the tissues, but in some cases their presence also favours the development of a higher degree of virulence of the former.

These facts established by experiment (and many others might be given), illustrate the important part which local or general conditions of diminished vitality may play in the production of disease in the human subject. This has long been known by clinical observation. In normal conditions the blood and tissues of the body, with the exception of the skin and certain of the mucous surfaces, are bacterium-free, and if a few organisms gain entrance, they are destroyed. But if the vitality becomes lowered their entrance becomes easier and the possibility of their multiplying and producing disease greatly increased. In this way the favouring part played by fatigue, cold, etc., in the production of diseases of which the direct cause is a bacterium, may be understood. The action of a certain organism may devitalise the tissues to such an extent as to pave the way for the entrance of other bacteria; we may mention the liability of the occurrence of pneumonia, erysipelas, and various suppurative conditions in the course of or following infective fevers. In some cases the specific organism may produce lesions through which the other organisms gain entrance, *e.g.*, in typhoid, diphtheria, etc. It is not uncommon to find in the bodies of those who have died from chronic wasting disease, collections of micro-cocci or bacilli in the capillaries of various organs, which have entered in the latter hours of life; that is to say, the bacterium-free condition of the blood has been lost in the period of prostration preceding death.

The methods by which the natural resistance may be increased belong to the subject of immunity, and are described in the chapter on that subject.

Modes of Bacterial Action.—In the production of disease by micro-organisms there are two main factors

involved, namely, in the first place, the multiplication of the living organisms after they have entered the body, and, in the second place, the production by them of poisons which may act both upon the tissues around and upon the body generally. The former corresponds to *infection*, the latter is of the nature of *intoxication* or poisoning. In different diseases one of these is usually the more prominent feature, but in all, both are more or less concerned.

1. *Infection and Distribution of the Bacteria in the Body.*—After pathogenic bacteria have invaded the tissues, or in other words after infection by bacteria has taken place, their further behaviour varies greatly in different cases. In the lower animals various forms of septicæmia may be produced, attended by an extensive multiplication of the organisms in the blood throughout the body (for example, the septicæmia produced by the pneumococcus in rabbits), but in septicæmia in man, the multiplication very seldom, if ever, occurs to so great a degree. For though the organisms may enter the blood stream and are carried by it to various organs, they rarely remain in large numbers in the circulating blood, and their detection in it during life by microscopic examination, and even by culture methods, is rare. In such cases, however, the organisms may be found *post mortem* lying in large numbers within the capillaries of various organs, *e.g.*, in cases of septicæmia produced by streptococci. (Relapsing fever forms an exception, as in it numerous organisms may be seen in a drop of blood.) In the human subject usually one of two things happens. In the first place, the organisms may remain local, producing little reaction around them, as in tetanus, or a well-marked lesion, as in diphtheria. Or in the second place, they may pass by the lymph or blood stream to other parts or organs in which they settle, multiply, and produce lesions, as in tubercle.

2. *Production of Chemical Poisons.*—In all these cases the growth of the organisms is accompanied by the formation of *chemical products*, which act generally or locally to a greater or less extent as toxic substances. The toxic

substances become diffused throughout the system, and their effects are manifested chiefly by symptoms such as the occurrence of fever, disturbances of the circulatory, respiratory, and nervous systems, etc. In some cases corresponding changes in the tissues are found, for example, the changes in the nervous system in diphtheria, to be afterwards described. The general toxic effects may be so slight as to be of no importance, as in the case of a local suppuration, or they may be very intense as in tetanus, or again, less severe but producing cachexia by their long continuance, as in tuberculosis. The nature of these chemical products and their mode of formation will be afterwards considered, but it may be stated here that they are not, at least in every case, of the nature of simple secretions by the bacteria. They may be formed directly by the bacteria or indirectly by the medium of ferments. A considerable number of the general toxic effects in different diseases can be experimentally reproduced by injection of the products of the organisms obtained from cultures grown outside the body.

The occurrence of *local tissue changes or lesions* produced in the neighbourhood of the bacteria as already mentioned, is one of the most striking results of bacterial action, but these also must be traced to chemical substances formed in or around the bacteria, and either directly or through the medium of ferments. In this case it is more difficult to demonstrate the mode of action, for, in the tissues the chemical products are formed by the bacteria slowly, continuously, and in a certain degree of concentration, and these conditions cannot be exactly reproduced by experiment. Further, it is very doubtful whether all the chemical substances formed by a certain bacillus growing in the tissues are also formed by it in cultures outside the body.

The injection of large quantities of many different pathogenic organisms in the *dead* condition results in the production of a local inflammatory change which may be followed by suppuration, this effect being possibly brought about by certain substances in the bacterial proto-

plasm common to various species, or at least possessing a common physiological action (Buchner and others). When dead tubercle bacilli, however, are introduced into the blood stream, nodules do result in certain parts which have a resemblance to ordinary tubercles. In this case the bodies of the bacilli evidently contain a highly resistant and slowly acting substance which gradually diffuses around and produces effects (*vide* Tuberculosis). It may be here pointed out that there is, however, no relation between the toxic effects of an organism and the extent to which it invades the tissues. Some of the organisms which produce the most highly toxic effects have a comparatively localised sphere of growth in the tissues, and others multiply with great freedom throughout the blood, while their toxic effects in proportion to their number are small. Compare, for example, the behaviour of the anthrax bacillus with that of the diphtheria bacillus. But there is, on the other hand, no known example of a bacterium multiplying in the living tissues without producing distinct local or general effects.

The action of bacteria as mechanical irritants plays a very small part in the processes of disease; and the differences in their effects, though regulated by the position and rate of growth of the organisms, can be accounted for only by the formation of definite chemical substances which act on the tissues.

Summary.—We may say then that the action of bacteria as disease-producers, as in fact their power to exist and multiply in the living body, depends upon the chemical products formed directly or indirectly by them. This action is shown by *tissue changes* produced in the vicinity of the bacteria or throughout the system, and by *toxic symptoms* of great variety of degree and character.

We shall first consider the effects of bacteria on the body generally, and afterwards the nature of the chemical products.

Effects of Bacterial Action.

These may be for convenience arranged in a tabular form as follows:—

Tissue Changes.

(1) Local changes, *i.e.*, changes produced in the neighbourhood of the bacteria.

Position (*a*) At primary lesion.
(*b*) At secondary foci.

Character (*a*) Vascular changes and tissue reactions. } Acute or
(*b*) Degeneration and necrosis. } Chronic.

(2) Produced at a distance from the organisms by absorption of toxines.

(*a*) In special tissues, *i.e.*, nerve fibres, secreting cells, vessel walls, etc.
(*b*) General effects of malnutrition, etc.

Symptoms.

(*a*) Associated with known tissue changes.
(*b*) Without known tissue changes.

Tissue Changes Produced by Bacteria.—The action of bacteria on the tissues will be more minutely described in connection with the special diseases, but here a general outline of their more important effects may be given. These effects are so various as to include almost all known pathological changes, but they may be classified as local effects or lesions produced in the neighbourhood of the bacteria, and general changes which are produced in various parts of the system by the circulation of the bacterial products. As already stated, both the local and the general effects are due to the products of the organisms, but the substances which produce local disturbances may not be the same in more concentrated form as these which act on distant parts of the system. In diphtheria, for example, the products

which produce the local inflammatory reaction and necrosis are probably not the same as those which act on the secreting cells of the kidney or on the nerve fibres.

Further, it may be again stated that the action of the products circulating in the system is often manifested more by symptoms than by tissue changes, though our knowledge of the latter, especially in the nervous system, is gradually being extended. The proportion of tissue change to toxic phenomena varies very widely in the case of different organisms. Leprosy may be mentioned as a disease in which the local lesions may be very widespread, and the number of bacilli enormous, with comparatively little accompanying constitutional disturbances, whilst tetanus is an example which presents quite a converse condition.

(1) *Local Lesions.*—By this term is meant the changes produced in the neighbourhood of the bacteria. These changes are, on the one hand, of the nature of *inflammatory reaction*, from the most intense vascular changes in acute inflammations to the more or less chronic proliferative changes especially of connective tissue, and, on the other hand, of the nature of *cell-poisoning*, leading to degeneration or necrosis, especially of the more highly-developed elements. They may be roughly classified as acute and chronic changes. As already pointed out, it must be borne in mind that in the case of a given organism, the effects vary in different animals, and further, where the lesion is approximately the same in different animals, differences in their minor characters may be found. Examples of this latter are furnished in the case of tubercle.

Position of Lesions.—In some diseases the lesion has a special site; for example, the lesion of typhoid fever and, to a less extent, that of diphtheria. In other cases it depends entirely upon the point of entrance, *e.g.*, malignant pustule and the conditions known as wound infections. In others again, there is a special tendency for certain parts to be affected, as the upper parts of the lungs in tubercle. In some cases the site has a mechanical explanation.

When organisms gain an entrance to the blood from a

primary lesion, directly or by the lymphatic system, they may become destroyed, or they may settle in certain organs and produce their characteristic effects. The organs specially liable to be affected in this way vary in different diseases. Pyogenic cocci show a special tendency to settle in the capillaries of the kidneys and produce miliary abscesses, whilst these lesions rarely occur in the spleen. In the spleen, on the other hand, the nodules in disseminated tubercle or glanders are much more numerous than in the kidneys, which in the latter disease are usually free from such. The important point is that the position of the disseminated lesions is not to be explained by a mechanical process, such as embolism, but depends upon a special relation between the organisms and the tissues, which may be spoken of either as a selective power on the part of the organisms or a special susceptibility of tissues, possibly in part due to their affording to the organisms more suitable conditions of nutriment. Experimentally, it has been shown in the case of many organisms that when injected into the circulation, they disappear from the blood in a comparatively short time, and are found in the capillary walls especially in internal organs. Many are destroyed and disappear, but at certain places they may multiply and produce lesions. Even in the case of the lesions produced by dead tubercle bacilli, a certain selective action is found.

Acute Local Lesions.—The local inflammatory reaction presents different characters in different conditions. It may be accompanied by abundant fibrinous exudation, or by great catarrh (in the case of an epithelial surface), or by hæmorrhage, or by œdema; it may be localised or spreading in character; it may be followed by suppuration, or may lead to necrosis. A few examples may be given. A great many different organisms cause an abundant fibrinous exudation. This, along with necrosis of epithelium, is the action of the diphtheria bacillus on a mucous membrane, and also of streptococci in certain conditions; it is produced in the alveoli of the lung in croupous pneumonia by the pneumococcus and probably by other

organisms, whilst fibrinous inflammation in serous cavities is produced by a great many different bacteria. The last statement also applies to numerous suppurative and catarrhal conditions. The inflammatory change in a Peyer's patch in typhoid fever, though fibrinous exudation is less marked, is followed by necrosis, while in the malignant pustule of man, necrotic change attended by considerable hæmorrhage is one of the chief features. The great variety in local reaction is well illustrated in the case of skin lesions produced by bacteria. The necrotic or degenerative changes affecting especially the more highly developed elements are chiefly produced by the direct action of the bacterial poisons, though aided by the disturbances of nutrition involved in the vascular phenomena.

In many of the acute inflammatory conditions, if not attended by a fatal result, the disease comes to a natural termination after a certain time, *e.g.*, in pneumonia, erysipelas, etc. These facts, the explanation of which is not yet fully understood, have an important relation to the subject of immunity, and will be discussed later. It may also be pointed out that a well-marked inflammatory reaction is often found in animals which occupy a medium position in the scale of susceptibility, and that a given organism which causes a general infection in a certain animal may produce only a local inflammation when its virulence is lessened.

Chronic Local Lesions.—In a considerable number of diseases produced by bacteria the local tissue reaction is a more chronic process than those described. In other words, the specific irritant is less intense, so that there are less acute inflammatory changes and a greater preponderance of the proliferative processes, leading to new formation of tissue. This formation may occur in foci here and there, so that nodules of greater or less consistence result, or it may be more diffuse. Such changes especially occur in the diseases often known as the *infective granulomata*, of which tubercle, leprosy, glanders, actinomycosis, syphilis, etc., are examples. A hard and fast line, however, cannot

be drawn between such conditions and those described above as acute. In glanders, for example, the lesion produced by the glanders bacillus often approaches very nearly to an acute suppurative change, and sometimes actually is of this nature. In all these diseases the fundamental change is the same, viz., a reaction to an irritant of minor intensity. The exact structural characters and arrangement, however, vary in different diseases, so that in some cases the disease may be identified by the histological changes alone, without a bacterial examination, but on the other hand, this is often impossible. In tubercle, for example, in addition to the proliferative change, a cellular necrosis is produced by the bacilli, leading ultimately to caseation, whereas the latter does not occur in leprosy, though a certain amount of degeneration and vacuolation of cells may be found. In tubercle, giant-cells of somewhat characteristic appearance are found; in leprosy, large rounded cells often called "lepra-cells" occur in large numbers; in actinomycosis bovis, there is an extensive growth of spindle-celled granulation tissue which may form large masses, and so on. Infection of other parts from the primary lesion takes place chiefly by the blood vessels and lymphatics, though sometimes along natural tubes such as the bronchi, intestine, etc. The organs specially liable to be the site of secondary lesions vary in different diseases, as already explained.

(2) *General Lesions produced by Toxines.*—In the various infective conditions produced by bacteria, changes commonly occur in certain organs unassociated with the presence of the bacteria, and these are no doubt produced by the action on the tissues of bacterial products circulating in the blood. Many such lesions can be produced experimentally. The secreting cells of various organs, especially the kidney and liver, are specially liable to change of this kind. Cloudy swelling, which may be followed by fatty change or by actual necrosis with granular disintegration, is often seen. Hyaline change in the walls of arterioles may occur, and in certain chronic conditions waxy change is probably brought

about in a similar manner. The latter has been produced in animals by the repeated injection of the staphylococcus aureus. Capillary hæmorrhages are not uncommon, and are in many cases due to an increased permeability of the vessel walls, aided by changes in the blood plasma, as evidenced sometimes by diminished coagulability. Similar hæmorrhages may follow the injection of some bacterial toxines, *e.g.*, of diphtheria, and also of vegetable poisons, *e.g.*, ricin and abrin. Skin eruptions occurring in the exanthemata are probably produced in the same way, though in many of these diseases the causal organism has not yet been isolated. And further, we have the fact that corresponding skin eruptions may be produced by poisoning with certain drugs. In the nervous system degenerative changes have been found in diphtheria, both in the spinal cord and in the peripheral nerves, and have been reproduced experimentally by the products of the diphtheria bacilli. There is also experimental evidence that the bacillus coli communis and the streptococcus pyogenes may, by means of their products, produce areas of softening in the spinal cord, and this may furnish an explanation of some of the lesions found clinically. It is also possible that some serous inflammations may be produced in the same way. General malnutrition and cachexia are, of course, a common occurrence, and it is a striking fact found by experiment that after injection of bacterial products, *e.g.*, of the diphtheria bacillus, a marked loss of weight often occurs which may be progressive, and ultimately lead to the death of the animal.

Symptoms. — Many of the symptoms occurring in bacterial affections are produced by the histological changes mentioned, as can be readily understood; whilst in the case of others, corresponding changes have not yet been discovered. Of the latter, fever, with its disturbances of metabolism and manifold affections of the various systems, is the most important. The nervous system is especially liable to be affected—convulsions, spasms, coma, paralysis, etc. being common. The secretory function of

the glands of the alimentary canal, of the salivary glands, may be disturbed or practically stopped,—a striking analogy to what is found in the action of various drugs.

These tissue changes and symptoms are given only as illustrative examples, and the list might easily be greatly amplified. The important fact, however, is that nearly all, if not quite all, the changes found throughout the organs (without the actual presence of bacteria), and also the symptoms occurring in infective diseases, can either be experimentally reproduced by the injection of bacterial poisons or have an analogy in the action of drugs.

The Toxines Produced by Bacteria.

We know that bacteria are capable of giving rise to poisonous bodies within the animal body and also in artificial media. As we shall see, we know comparatively little of the actual nature of such bodies, and therefore we apply to them as a class the general term *toxines*. The fact that in the case of many diseases, undoubtedly caused by bacteria, the latter were not distributed throughout the body, directed attention to the necessity for the existence of such toxines in order to explain the general pathogenic effects occurring in such circumstances. The first to systematically study the production of poisonous bodies by bacteria was Brieger. This observer, directing attention to general putrefactive processes as they occurred under natural conditions, *e.g.*, in putrefying flesh, etc., isolated a series of crystalline nitrogen-containing bodies giving the reactions of alkaloids, and which he called *ptomaines*. Similar bodies occurring in the ordinary metabolic processes of the body had previously been described and called *leucomaines*. Brieger further isolated ptomaines from media containing pure cultures of many of the pathogenic bacteria. These ptomaines, however, on being injected into animals susceptible to the corresponding diseases, in no case except, perhaps, in tetanus, reproduced characteristic symptoms;

and even in tetanus the effects produced only bore a distant resemblance to those caused by the injection of the bacillus itself. Brieger's methods of obtaining these bodies were open to much criticism. The chemical processes entailed were of a highly complicated character. They commenced with a treatment of the crude material with acids under heat, and this alone was shown to be sufficient to cause serious changes in the complex albuminous bodies present. The possibilities of similar changes occurring in the subsequent stages of the analyses also existed, and this, taken along with the failure of the bodies to reproduce the toxic symptoms of their respective diseases, renders it unnecessary for us to look on them as of other than a historic interest.

The introduction of the principle of rendering fluid cultures bacteria-free by filtration through porcelain, and its application by Roux and Yersin to obtain, in the case of the B. diphtheriæ, a solution containing a toxine which reproduced the symptoms of this disease (*vide* Chap. XV.), encouraged the further inquiry as to the nature of this toxine. The products of the B. diphtheriæ were investigated again by Brieger, now in conjunction with C. Fraenkel. The filtrate was evaporated to a third of its bulk in vacuo, at a temperature not exceeding 30° C., and was precipitated by alcohol. The precipitate was redissolved in water, reprecipitated by alcohol, and this operation being repeated six to eight times a final product in the form of a snow-white mass was obtained. The chemical procedure was thus in principle simple, and the toxine at every stage stood the two tests given by the original fluid, namely (1) its specific toxicity to animals, and (2) destruction of its toxic power by two hours' exposure to a temperature of 58° C. This substance, if it did not consist entirely of the diphtheria toxine, certainly contained the latter, and from resemblances they observed in it to serum albumin, was called by its discoverers a *toxalbumin*. Brieger and Fraenkel, working with the same methods, obtained similar toxic bodies from the bacteria of tetanus, typhoid, and cholera, and also from

the staphylococcus aureus. In the case of tetanus, as in diphtheria, rigorous tests could be applied to determine whether the substance isolated was the toxine, and in the one experiment recorded, where the toxalbumin was injected into a guinea-pig, death with spasms and paralysis resulted. In the case of the toxalbumins of the other organisms death occurred from their injection, but no characteristic symptoms or pathological effects took place. These toxalbumins presented no special chemical reaction, though the authors considered them allied to serum albumin. They probably consisted largely of albumoses,[1] whose presence is to be accounted for, partly by the fact that the ordinary bacteriological media were used as the culture fluid, partly by the fact that they were produced by the digestive action of the bacteria investigated. They contained the toxic bodies in mixture with other substances.

The analogies between the modes of bacterial action and what takes place in ordinary gastric digestion have already been indicated, and these have been very fully worked out for certain pathogenic bacteria by Sidney Martin. This observer took, not solutions artificially made up with albumoses, but the natural fluids of the body or definite solutions of albumins, and, further, never subjected the results of the bacterial growth to heat above 40° C.

[1] In the digestion of albumins by the gastric and pancreatic juices the albumoses are a group of bodies formed preliminarily to the elaboration of peptone. Like the latter they differ from the albumins in their not being coagulated by heat, and in being slightly dialysable. They differ from the peptones in being precipitated by dilute acetic acid, in presence of much sodium chloride, and also by neutral saturated sulphate of ammonia. Both are precipitated by alcohol. The first albumoses formed in digestion are proto-albumose and hetero-albumose, which differ in the insolubility of the latter in hot and cold water (insolubility and coagulability are quite different properties). They have been called the primary albumoses. By further digestion both pass into the secondary albumose, deutero-albumose, which differs slightly in chemical reactions from the parent bodies, *e.g.*, it cannot be precipitated from watery solutions by saturated sodium chloride unless a trace of acetic acid be present. Dysalbumose is probably merely a temporary modification of hetero-albumose. Further digestion of deutero-albumose results in the formation of peptone.

nor to any stronger agent than absolute alcohol. He showed that albumoses and sometimes peptones were formed by the action of the pathogenic bacteria studied, and further, that these albumoses were toxic. In certain cases the process of splitting up of the albumins went further than in peptic digestion, and organic bases or acids might be formed. The characteristic symptoms of the diseases could be explained by compound actions, in which the albumoses were responsible for some of the effects, the other bodies for others. The precise effects produced in the cases studied by Martin will be taken up under the diseases he investigated. A similar digestive action has been traced in the case of the tubercle bacillus by Kühne.

The comparison of the action of bacteria in the tissues in the production of these toxines to what takes place in gastric digestion, raises the question of the possibility of the elaboration by these bacteria of *ferments* by which the process may be started. The problem of toxine formation is thus still further complicated. Martin has described toxic albumoses as occurring in all the diseases he investigated, viz. anthrax, ulcerative endocarditis, diphtheria, and tetanus. In each of these cases, therefore, we would be led to suppose that primarily ferments might be produced. Martin carries the analogy to the full, and suggests that, just as by the secretion of ferments into the intestine, the non-soluble albumins of the food are transformed into the soluble albumoses and peptones which are easily absorbed by the intestinal cells, so it is likely that bacteria may excrete ferments which, acting on the albumins in which they are living, may make the latter more available for subsequent absorption as food. Looked at from the side of the animal in or on which the bacteria are living, these products of digestion are toxic, and it is evident that, given a diffusible ferment, we may look on it as the primary toxic agent which acts by producing secondary non-diastatic poisons. There is evidence in some cases that such toxine-producing ferments actually exist, though hitherto all attempts at their isolation in a pure condition have failed.

The two diseases in which they most probably exist are diphtheria and tetanus. Apart from the evidence that a digestive action has occurred, which the presence of albumoses in the body of an animal dead of these diseases affords, the chief available evidence for the existence of ferments lies in the fact, that the toxic products of the bacteria involved lose their toxicity by exposure to a temperature which puts an end to the diastatic activity of such an undoubted ferment as that of the gastric juice. If a bouillon in which the B. diphtheriæ has been growing be filtered germ-free it is toxic, and reproduces the symptoms of the disease when injected into animals. If such a bouillon be heated at 65° C. for one hour, it is found to have lost much of its toxic effect. There is evidence, however, that there remains a substance unaffected by the heat which, as we shall see later, is also toxic. In the case of the B. tetani growing in artificial media similarly treated, all the toxicity is lost by exposure at 65° C.; but there is some evidence that in tetanus, as it occurs in animals, there are bodies present in the tissues which are not destroyed by heat, and which give rise to the characteristic toxic effects which manifest themselves in the disease. In this disease there is a still further fact which leads us to suppose that a ferment is concerned in the toxic action, namely, the existence of a definite period of incubation between the injection of the toxic bodies and the appearance of symptoms. This may be interpreted as showing that after the introduction of say a filtered bouillon culture, further chemical changes have to be set up in the body before the direct effect in stimulating the nervous system, which is the essential feature in the disease, is produced. Strychnine has probably a very similar effect to that of the body which produces the spasms in tetanus, but if strychnine be injected into an animal the effect is practically immediate. In tetanus we have the further interesting fact that, according to one set of observations, the substance existing in the tissues of a tetanic animal, to which reference has been made as not being destroyed by heat, has such an immediate effect without the intervention of an incubation

period. Similar toxic bodies not destroyed by heat also exist in the case of the tubercle bacillus and the cholera vibrio. Thus toxine formation may be a very complicated process, and in many cases the elaboration of a ferment may be necessary. If this ferment be injected into a fresh animal it may give rise, by a process of digestion, to toxic substances of a non-diastatic nature. The injection of the latter, derived from previous digestive action outside an animal's body, would also give rise to toxic effects. The relation of ferments to toxine production is one on which much further research is necessary. The important fact, however, to be noted is that in certain cases there is evidence of the existence of two classes of toxic bodies: first, a group the activity of which is destroyed by heat, and secondly, a group which are more resistant to heat. The first may be ferments, and may be the originators of the second, though complete proof is still wanting.

Brieger and Boer, working with bouillon cultures of diphtheria and tetanus, have lately, by a special method, the essential feature of which is precipitation by certain metallic salts, especially zinc chloride, separated bodies which show characteristic toxic properties, but which have the reactions neither of peptone, albumose, nor albuminate, and the nature of which is unknown. Such bodies may, on the one hand, be the final product of a digestive action, or they may be the manifestation of a separate vital activity on the part of the bacteria. On the latter theory the toxicity of the toxalbumins of Brieger and Fraenkel, and of the toxic albumoses of Martin may be due to the precipitation of the true toxines along with these other bodies. From the chemical standpoint this is quite possible. Rather in support of such a possibility are the facts that the bacteria of tubercle, tetanus, diphtheria, and cholera can produce toxines when growing in proteid-free fluids. The toxines may, therefore, be formed within the bacteria and not be the result of the breaking down of the proteids, etc., on which the bacteria are living.

The relations of toxic bodies to the bacterial cell on the

one hand, and to the medium in which the latter may be growing is a subject which has received considerable attention, and *intracellular* as distinguished from *extracellular* poisons have been spoken of. The main difference between such depends on whether a poison is or is not easily diffusible into the artificial or natural food medium of the bacterium, though of course if Martin's view on the formation of toxic albumoses by digestion is correct, these latter not only exist extracellularly, but are also probably formed outside the cell. Great differences exist in the diffusibility of bacterial poisons into artificial media. Thus both with the B. diphtheriæ and the B. tetani a filtered bacteria-free bouillon culture is very toxic. A bouillon culture, similarly treated, from the B. anthracis is relatively non-toxic, and Pfeiffer found the same to be true of the vibrio of Massowah (one of the cholera group). There is evidence that not only poisons injured by heat but those uninjured by heat may exist intracellularly. Thus, if the bodies of tubercle bacilli killed by heat be injected into an animal, tubercular nodules are formed round them, from which it is inferred that they must have contained characteristic toxines, seeing that characteristic lesions result. The bodies of the cholera vibrio are also similarly toxic. Too much stress must not, however, be laid upon the difference between intracellular and extracellular poisons, for as a matter of practice in any medium derived from bacteria both must be present. In a bouillon culture of a bacterium containing non-diffusible toxines the death of great numbers of bacteria, which is constantly taking place in every culture, results in the disintegration of their bodies and the passing of the material they contained into the culture fluid. On the other hand, a scraping from the surface of say an agar culture of a bacterium forming diffusible toxines will necessarily contain these toxines from the fact that a certain quantity of free fluid will always be present.

Summary.—To sum up our knowledge of this subject. The word toxine is a very general term, and the bodies to which it is at present applied are probably of different

natures. Such bodies are undoubtedly formed by pathogenic bacteria, and several different kinds, differing in their pathogenic effects, may be produced by one bacterium. While digestion of albumins by pathogenic bacteria does occur, the toxicity of the products of such digestion may be due to the true toxines being merely adherent to such products. The ultimate true toxines may not present the properties of albumin, peptone, or albuminate. In some cases the bacterial product primarily concerned in toxine-formation is very probably a ferment, which secondarily may give rise to non-diastatic bodies which are active toxic agents. Further, poisons formed within the bacterial cell may, during the life of the bacterium, only to a small extent, diffuse into the surrounding fluid. Finally, the action of every species of bacterium must be studied by itself, as the pathogenic *modus operandi* probably differs in different cases.

CHAPTER VI.

SUPPURATION AND ALLIED CONDITIONS.

THE subject of suppuration is an exceedingly wide one, and embraces a great many pathological conditions which in their general characters and results are widely different. Thus bacteriological research has shown that the same organism may in one case produce a simple local abscess of trifling importance, in another case multiple spreading suppurations in various organs, or again, under different conditions, an ulcerative endocarditis. The study of the pus-producing or pyogenic organisms, their paths of entrance, and their effects on the tissues, constitutes one of the most important subjects in pathology. Suppuration will first be treated of in general, and afterwards reference will be made to some conditions which, on account of their importance, have received special names, *e.g.*, acute osteomyelitis, ulcerative endocarditis, etc.

Nature of Suppuration.—Suppuration is not a specific disease, but rather a pathological condition which follows inflammation under certain circumstances. The process is best studied in the subcutaneous tissue or in a solid organ, such as the kidney, and it is found that the following factors are involved. Consequent on the inflammatory condition, there occur in the part affected (*a*) a progressive immigration and accumulation of leucocytes, chiefly those with multipartite nucleus (the so-called "multinucleated" leucocytes); (*b*) degeneration followed by necrosis of the special

cells of the part, those most highly organised being affected first; and (*c*) a liquefaction or digestion of the supporting elements of the tissue. Any previously-formed fibrin is also softened and disappears. The result is that the solid tissue becomes replaced by the cream-like fluid called pus, a fluid which does not coagulate, and in which the chief cellular elements are multinucleated leucocytes, along with the degenerated cells of the part. Suppuration is therefore to be distinguished, on the one hand, from a severe inflammation, in which, however, the tissue is not destroyed, and on the other hand, from necrosis or death of the tissue *en masse*. When, however, suppuration is taking place in a very dense fibrous tissue, liquefaction may be incomplete, and a portion of dead tissue or slough may remain in the centre, as is the case in boils. In the case of suppuration in a serous cavity the two chief factors are the progressive leucocytic accumulation and the disappearance of any fibrin which may be present.

The liquefaction of the formed tissue elements in suppuration is believed to depend upon a peptonising action of the organisms or of ferments produced by them, and the progressive leucocytic aggregation is explained by many as also being the effect of microbic products which attract the leucocytes, or in other words exert a *positive chemiotaxis*. We might expect that any organisms which could flourish in the tissues and exert these actions would produce suppuration, and as a matter of fact a considerable number have been found to possess pyogenic properties.

The terms *septicæmia* and *pyæmia* may be first explained, as these will be frequently used. Septicæmia is applied to conditions in which the organisms multiply within the blood and give rise to symptoms of general poisoning, without, however, producing abscesses in the organs. It is to be distinguished from conditions in which there is a merely local growth of bacteria, the symptoms being produced by absorption of their toxines. In all cases of septicæmia the organisms are more numerous in the capillaries of certain organs than in the peripheral circulation, and, in the case

of the human subject, it is often impossible to detect any in the blood taken by puncture of the skin during life, though they may be seen in large numbers in the capillaries of the kidneys, liver, etc., *post mortem*. The best examples of extensive bacterial multiplication in the circulating blood are afforded by certain infections of the lower animals, *e.g.*, anthrax in guinea-pigs or pneumococcus septicæmia in rabbits. The essential fact in pyæmia, on the other hand, is the occurrence of multiple abscesses in internal organs and other parts of the body. In most of the cases of typical pyæmia, common in the pre-antiseptic days, the starting-point of the disease was a septic wound with bacterial invasion of a vein leading to thrombosis and secondary embolism. Multiple foci of suppuration may be produced, however, in other ways, as will be described below (p. 161). If the term be used to embrace all such conditions, their method of production should always be distinguished.

The Bacteria of Suppuration.

A considerable number of bacteria have been described as occurring in the pus of acute suppurations, and of these many have been proved to be the causes of the condition, whilst of some others the exact action has not yet been fully determined.

Ogston, who was one of the first to study this question (in 1881), found that micrococci were most frequently present, and that of these some were arranged irregularly in clusters (staphylococci), whilst others formed chains (streptococci). He found that the former were more common in circumscribed acute abscesses, the latter in spreading suppurative conditions. Rosenbach shortly afterwards (1884), by means of cultures, differentiated several varieties of micrococci, to which he gave the following special names: *staphylococcus pyogenes aureus*, *staphylococcus pyogenes albus*, *streptococcus pyogenes*, *micrococcus pyogenes tenuis*. Other organisms have since been described as associated with suppuration, such as

staphylococcus pyogenes citreus, *staphylococcus cereus albus*, *staphylococcus cereus flavus*, *bacillus pyogenes fœtidus* (Passet), *bacillus coli communis*, *bacillus pyocyaneus*, *micrococcus tetragenus*, *pneumococcus*, *pneumobacillus*, and others.

In secondary suppurations following acute specific diseases the corresponding organisms have been found in some cases, such as gonococcus, pneumococcus of Fraenkel, pneumobacillus of Friedländer, and the typhoid bacillus.

Suppuration is also produced by the actinomyces and the glanders bacillus, and sometimes chronic tubercular lesions have a suppurative character.

Staphylococcus Pyogenes Aureus.—*Microscopical Characters.*—This organism is a spherical coccus about .9 μ in diameter, which grows irregularly in clusters or masses (Fig. 40). It stains readily with all the basic aniline dyes, and retains the colour in Gram's method.

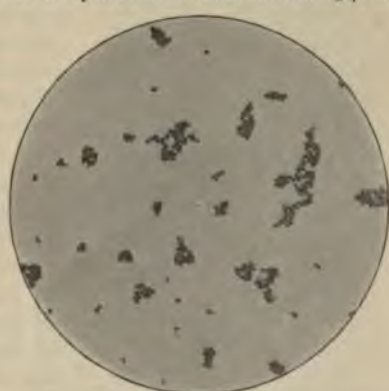

FIG. 40.—Staphylococcus pyogenes aureus, young culture on agar, showing clumps of cocci.
Stained with weak carbol-fuchsin. × 1000.

Cultivation. — It grows readily in all the ordinary media, growth taking place at the room temperature, though it is much more rapid at the temperature of the body. In stab cultures on *peptone gelatine* a streak of growth is visible on the day after inoculation, and on the second or third day liquefaction commences at the top. As liquefaction proceeds, the growth falls to the bottom as a flocculent deposit, which soon assumes a bright-yellow colour, while a yellowish film may form on the surface, the fluid portion, however, remaining turbid. Ultimately the gelatine becomes liquefied

out to the wall of the tube (Fig. 41). In *gelatine plates* colonies may be seen with the low power of the microscope in twenty-four hours, as little balls somewhat granular on the surface and of brownish colour. On the second day they are visible to the naked eye as whitish-yellow points, which afterwards become more distinctly yellow. Liquefaction occurs around these, and little cups are formed, at the bottom of which the colonies form little yellowish masses. On *agar*, a stroke culture forms a line of abundant opaque growth, with smooth, shining surface, well formed after twenty-four hours at 37° C. Later it becomes bright orange in colour, and resembles a streak of yellow oil paint. Single colonies on the surface of agar are circular discs of similar appearance, which may reach 2 mm. or more in diameter. On *potatoes* it grows well at ordinary temperature, forming a somewhat abundant layer of orange colour. In *bouillon* it produces a uniform turbidity, which afterwards settles to the bottom as an abundant layer which assumes a brownish-yellow tint. In the various media it renders the reaction acid, and it coagulates milk, in which it readily grows. The cultures have a somewhat sour odour.

FIG. 41.—Two stab cultures of staphylococcus pyogenes aureus in gelatine, (*a*) 10 days old, (*b*) 3 weeks old. Showing liquefaction of the medium and characters of growth. Natural size.

It has considerable tenacity of life outside the body, cultures in gelatine often being alive after having been kept

for several months. It also requires a rather higher temperature to kill it than most spore-free bacteria, viz. 80° C. for half an hour (Lübbert).

The Staphylococcus pyogenes albus is similar in character with the exception that its growth on all the media is white. The colour of the staphylococcus aureus may become less distinctly yellow after being kept for some time in culture, but it never assumes the white colour of the staphylococcus albus, and it has been found impossible to transform the one organism into the other. Both organisms are common in air, dust, and especially on the surface of the skin. The *staphylococcus pyogenes citreus* which is less frequently met with, differs in the colour of the cultures being a lemon yellow, and it is stated to be less virulent than the other two.

The *staphylococcus cereus albus* and *staphylococcus cereus flavus* are of much less importance. They produce a wax-like growth on gelatine without liquefaction, hence their name.

Streptococcus pyogenes.—This organism is a coccus of rather larger size than the staphylococcus aureus, about 1 μ in diameter, and forms chains which may contain a large number of members, especially when it is growing in fluids (Fig. 42). The chains vary somewhat in length in different specimens of the streptococcus, and on this ground varieties have been distinguished, *e.g.*, the streptococcus brevis and streptococcus longus (*vide infra*). As division may take

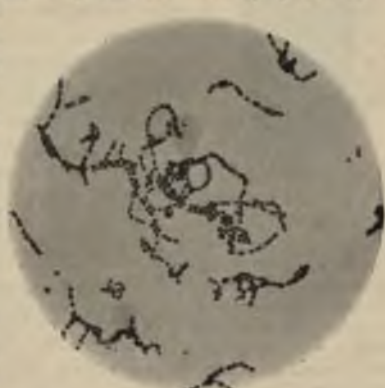

FIG. 42.—Streptococcus pyogenes, young culture on agar, showing chains of cocci. Stained with weak carbol-fuchsin. × 1000.

place in many of the cocci in a chain at the same time, the appearance of a chain of diplococci is often met with. In young cultures the cocci are fairly uniform in size, but after a time their size presents considerable variations, many swelling up to twice their normal diameter. These are to be regarded as involution forms. In its staining reactions the streptococcus resembles the staphylococci described.

FIG. 43. — Stroke culture of the streptococcus pyogenes on sloped agar, showing numerous colonies. The strokes were made directly from pus containing numerous streptococci in a pure condition. Three days' growth. Natural size.

Cultivation.—In cultures outside the body the streptococcus pyogenes grows much more slowly than the staphylococci, and also dies out more readily, being in every respect a more delicate organism.

In *peptone-gelatine* a stab culture shows, about the second day, a thin line which in its subsequent growth is seen to be formed of a row of minute rounded colonies of whitish colour, which are more clearly separate at the lower part of the puncture. They do not usually exceed the size of a small pin's head, this size being reached about the fifth or sixth day. The growth does not spread on the surface and no liquefaction of the medium occurs. The colonies in gelatine plates have a corresponding appearance, being minute spherical points of whitish colour. On the *agar* media, growth takes place along the stroke as a collection of small circular discs of semi-translucent appearance, which show a great tendency to remain separate (Fig. 43). The separate colonies remain small and do not usually exceed 1 mm. in diameter. Cultures on agar kept at the body temperature may often be found to be dead after ten days. On *potato*, as a rule, no

visible growth takes place. In *bouillon*, growth forms numerous minute granules which afterwards fall to the bottom, the deposit, which is usually not very abundant, having a sandy appearance. The appearance in broth, however, presents variations which have been used as an aid to distinguish different species of streptococci. It has been found that those which form the longest chains grow most distinctly in the form of spherical granules, those forming short chains giving rise to a finer deposit. To a variety which forms distinct spherules of minute size the term *streptococcus conglomeratus* has been given. The question as to the existence of varieties of streptococcus pyogenes will be discussed below.

The microscopic and cultural characters of the *bacillus coli communis* are described in the chapter on typhoid fever.

Bacillus Pyocyaneus.—This organism occurs in the form of minute rods 1.5 to 2 μ in length and less than .5 μ in thickness. Occasionally two or three are found attached end to end. They are actively motile, and do not form spores. They stain readily with the ordinary basic stains, but are decolorised in Gram's method.

Cultivation.—It grows readily on all the ordinary media at the room temperature, the cultures being distinguished by the formation of a greenish pigment. In puncture cultures in peptone-gelatine a greyish line appears in twenty-four hours, and at its upper part a small cup of liquefaction forms within forty-eight hours. At this time a slightly greenish tint is seen in the superficial part of the gelatine. The liquefaction extends pretty rapidly, the fluid portion being turbid and showing masses of growth at its lower part. The green colour becomes more and more marked and diffuses through the gelatine. Ultimately liquefaction reaches the wall of the tube. In plate cultures the colonies appear as minute whitish points, those in the surface being the larger. Under a low power of the microscope they have a brownish-yellow colour and show a nodulated surface, the superficial colonies being thinner and larger. Liquefaction soon occurs, the colonies on the surface forming shallow cups with small irregular masses of growth at the bottom, the deep colonies small spheres of liquefaction. Around the colonies a greenish tint appears. On agar the growth forms an abundant slimy greyish layer which afterwards becomes greenish, and a bright green colour diffuses through the whole substance of the medium. On potatoes the growth is an abundant reddish-brown layer resembling closely that of the glanders bacillus, and the potato sometimes shows a greenish discoloration.

From the cultures a coloured body pyocyanin can be extracted by chloroform, which belongs to the aromatic series, and crystallises in the form of long, delicate bluish-green needles. With the addition of a weak acid its colour changes to a red.

This organism has distinct pathogenic action in certain animals. Subcutaneous injection of small doses in rabbits may produce a local suppuration, but if the dose be large, spreading hæmorrhagic œdema results, which may be attended by a septicæmia, the organism occurring throughout the body. Intravenous injection may produce, according to the dose, rapid septicæmia with nephritis, or sometimes a more chronic condition of wasting attended by albuminuria.

Micrococcus Tetragenus.—This organism, first described by Gaffky, is characterised by the fact that it divides in two planes at right angles to one another (Fig. 44), and is thus generally found in the tissues in groups of four or tetrads, which are often seen to be surrounded by a capsule which stains faintly or not at all. The cocci measure 1 μ in diameter. They stain readily with all the ordinary stains and also retain the stain in Gram's method.

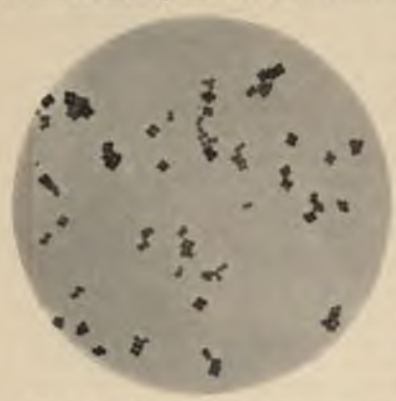

FIG. 44.—Micrococcus tetragenus; young culture on agar, showing tetrads. Stained with weak carbol-fuchsin. × 1000.

It grows readily on all the media at the room temperature. In a puncture culture on peptone-gelatine a pretty thick whitish line forms along the track of the needle, whilst on the surface there is a thick rounded disc of whitish-yellow colour. The gelatine is not liquefied. The colonies in gelatine plates are rounded yellowish-white points, which under a low power show a granular or slightly nodulated surface; the superficial colonies appear as opaque round drops of yellowish-white colour. On the surface of agar and of potato the growth is an abundant moist layer of the same colour. The growth on all the media has a peculiar viscid or tenacious character, owing to the gelatinous character of the sheaths of the cocci.

White mice are exceedingly susceptible to this organism. Subcutaneous injection is followed by a general septicæmia, the organism being found in large numbers in the blood throughout the body.

Guinea-pigs are less susceptible ; sometimes only a local abscess with a good deal of necrotic change results, sometimes, however, there is also septicæmia.

Experimental Inoculation.—We shall consider chiefly the staphylococcus pyogenes aureus and the streptococcus pyogenes, as these have been most fully studied.

It may be stated at the outset that the occurrence of suppuration depends upon the number of organisms introduced into the tissues, the number necessary varying not only in different animals (*e.g.*, suppuration being much more easily produced in rabbits than in dogs) but also in different parts of the same animal, a smaller number producing suppuration in the anterior chamber of the eye, for example, than in the peritoneum. The virulence of the organism also may vary, and corresponding results may be produced. Especially is this so in the case of the streptococcus pyogenes.

The *staphylococcus aureus*, when injected *subcutaneously* in suitable numbers, produces an acute local inflammation which is followed by suppuration, in the manner described above. The cocci multiply in the lymphatic spaces, and many are found within leucocytes and also invading the capillary walls. Wherever the condition is spreading the cocci are present in the tissues at the margin, but after it has ceased to spread they are practically confined to the pus. The spread of the suppuration goes *pari passu* with the growth of the cocci. When the suppuration has ceased to spread, we find reaction on the part of the connective tissues in the form of cellular proliferation and formation of new capillaries, which lead to the formation of a granulation tissue barrier. After this has been well formed the cocci are found to diminish gradually in numbers and finally they disappear. *Intraperitoneal* injection produces a suppurative peritonitis which may remain local, but which usually spreads and kills the animal.

Intravenous injection in rabbits, for example, produces interesting results which vary according to the quantity used. If a considerable quantity be injected, the animal may die in twenty-four hours of a general septicæmia,

numerous cocci being found in the capillaries of the various organs, in which they often form plugs. If a smaller quantity be used, the cocci gradually disappear from the circulating blood; some become destroyed, while others settle in the capillary walls in various parts and produce minute abscesses. These are most common in the kidneys, where they occur both in the cortex and medulla as minute yellowish areas surrounded by a zone of intense congestion, and often hæmorrhage. If one of these areas be examined microscopically before actual suppuration has occurred, it will be found that many of the capillaries are filled with cocci, and the tissues immediately around are necrosed, apparently by the action of the products of the organisms. At the margin of the necrosed area there is a dense zone of leucocytes. These gradually extend inwards and ultimately purulent softening of the area occurs. The cocci may reach the interior of the tubules, where they may be often seen mixed with leucocytes, and in this way they reach the bladder. Similar small abscesses may be produced in the heart wall, in the liver, under the periosteum, and in the interior of bones, and occasionally in the striped muscles. Very rarely indeed, in experimental injection, do the cocci settle on the healthy valves of the heart. If, however, when the organisms are injected into the blood, there be any traumatism of a valve or of any other part of the body, there will be produced a special tendency for them to settle at these weakened points. Though the organisms are frequently seen completely plugging the capillaries, it is to be noted that this is often the result of their multiplying after having settled in small numbers on the endothelium in specially susceptible organs. Further examples of the selection shown by different organisms for different parts will be given in subsequent chapters.

Experiments on the *human subject* have also proved the pyogenic properties of those organisms. Garré inoculated scratches near the root of his finger-nail with a pure culture, a small cutaneous pustule resulting; and by rubbing a culture over the skin of the forearm he caused a carbun-

cular condition which healed only after some weeks. Confirmatory experiments of this nature have been made by Bockhart, Bumm, and others.

When tested experimentally the staphylococcus pyogenes albus has practically the same pathogenic effects as the staphylococcus aureus.

The *streptococcus pyogenes* is an organism the virulence of which varies much according to the diseased condition from which it has been obtained, and which also loses its virulence rapidly in cultures. Even highly virulent cultures, if grown under ordinary conditions through several generations, in the course of time almost lose any pathogenic power. By passage from animal to animal, however, the virulence may be much increased, and *pari passu* the effects produced by it are correspondingly varied. Marmorek, for example, has found that its virulence can be enormously increased by growing it alternately (*a*) in a mixture of human blood serum and bouillon (*vide* page 50), and (*b*) in the body of a rabbit, till ultimately it possesses a supervirulent character, so that even a few streptococci introduced into the tissues of a rabbit produce rapid septicæmia with death in a few hours, the organisms being found in large numbers in the internal organs. It has been proved by Marmorek's experiments and those of others that the same streptococcus may produce at one time merely a passing local redness, at another a local suppuration, at another a spreading erysipelatous condition, or again a general septicæmic infection, according as its virulence is artificially increased. Such experiments are of extreme importance as explaining to some extent the great diversity of lesions in the human subject with which streptococci are associated.

Varieties of Streptococci.—It may be stated here that formerly the streptococcus pyogenes and the streptococcus erysipelatis were regarded as two distinct species, and various points of difference between them were given. Further study, and especially the results obtained by modifying the virulence, have shown that these distinctions

cannot be maintained, and now nearly all authorities are agreed that the two organisms are one and the same, erysipelas being produced when the streptococcus pyogenes of a certain standard of virulence gains entrance to the lymphatics of the skin.

Petruschky in a recent publication (1896) has shown conclusively that a streptococcus cultivated from pus may cause erysipelas in the human subject. He obtained a pure culture of a streptococcus from a case of purulent peritonitis secondary to parametritis, the patient never having suffered from erysipelas. By inoculations with this culture he produced typical erysipelas in two women suffering from cancer.

More recently a distinction has been drawn between a *streptococcus longus*, which corresponds to the streptococcus pyogenes, as it usually forms long chains, and is pathogenic to rabbits or mice, and a *streptococcus brevis*, which occurs in the mouth in normal conditions and is without pathogenic properties when tested experimentally. The growth of the former in bouillon forms a somewhat granular deposit, that of the latter a more abundant and flocculent deposit. Marmorek has, however, found that the same streptococcus may at one time grow in short, at another in long chains, and Kolle has shown that a streptococcus, which originally grew in long chains, formed only short chains after being repeatedly passed through the body of the mouse, and the appearance of the growth in bouillon was correspondingly altered. Further, Widal and Bezançon found that a streptococcus cultivated from the mouth and which was non-pathogenic, became pathogenic when inoculated along with the bacillus coli communis, and thereafter its virulence could be enormously increased by passing it through a series of animals. These latter observers also found that streptococci cultivated from the mouth of a smallpox patient were non-virulent, whilst those cultivated from the blood of the same patient *post mortem* were highly virulent, the probability being that those in the blood had been derived from those in the throat. There does not therefore seem at present sufficient evidence for looking upon these two varieties as distinct species. It is sufficient to bear in mind that streptococci in the normal mouth are usually non-virulent, and grow in short chains. On the other hand, in some cases of very virulent streptococcus infection in the human subject we have found the organism occurring only in very short chains. The *streptococcus conglomeratus*, so called from the appearance of the growth in bouillon, is to be regarded merely as another variety, which forms very long chains and is usually possessed of a high degree of virulence, though its distinctive characters are not permanent. It has often been obtained from the fauces in scarlet fever.

We may accordingly conclude that, though it cannot be definitely stated that all the streptococci concerned in the production of disease in the human subject are of the same species, there is at present no absolute means of distinguishing them.

Bacillus coli communis.—The virulence of this organism also varies much and can be increased by passage from animal to animal. Injection into the serous cavities of rabbits produces a fibrinous inflammation which becomes purulent if the animal lives sufficiently long. If, however, the virulence of the organism be of a high order, death takes place before suppuration is established, and there is a septicæmic condition, the organisms occurring in large numbers in the blood. Intravenous injection of a few drops of a virulent bouillon culture usually produces a rapid septicæmia with scattered hæmorrhages in various organs, though sometimes the animal recovers.

Other Effects.—It has been found by independent observers that in cases where rabbits recover after intravenous injection of bacillus coli communis, a certain proportion suffer from paralysis and sometimes from atrophy of muscles, especially of the posterior limbs, these symptoms being due to lesions of the cells in the anterior cornua of the spinal cord. Somewhat similar results have been obtained by others after inoculations with staphylococci and streptococci, a certain proportion only of the animals showing paralytic symptoms and corresponding changes in the spinal cord. The lesions are believed to be due chiefly to the action of the products of the organisms on the highly-organised nervous elements. Much further research requires to be done before the importance of these results can be properly estimated, but it is not improbable that they will throw light on the causation of nervous lesions which occur in the human subject, and the etiology of which at present is quite obscure. Some observers, chiefly of the French school, consider that paralysis associated with cystitis, in which the bacillus coli communis is often present, may have such a causation, and that paralytic conditions following acute infective fevers may be produced by the products of pyogenic cocci which are often present in these conditions.

Can Suppuration occur apart from Bacteria?—After it had been conclusively proved that bacteria were the chief causes of suppuration, a great many experiments were per-

formed to determine whether it could be produced by simple chemical substances, such as croton oil, nitrate of silver, mercury, etc. In these experiments various means have been employed to ensure the absence of bacteria. In some cases the chemical substance to be tested was placed in a closed glass capsule, which, after being sterilised, was inserted in the tissues and was not broken until the external wound had healed up; in other cases the capsule was made with pointed ends, so that it could be moved in the body of the animal to another part, and there broken. The general conclusion obtained by independent observers is that in these conditions suppuration usually does not follow, but that in certain animals and with certain chemical substances it may occur, the pus which forms showing no organisms on bacteriological examination. Such suppuration, however, never produces secondary abscesses in other parts, and it is still questioned by some whether the pus produced really corresponds histologically and chemically with pus naturally produced. Buchner showed that suppuration could be produced by injections of dead bacteria, for example, sterilised cultures of bacillus pyocyaneus, tubercle bacillus, and various others. The question, however, is now rather of scientific than practical interest, and the general statement may be made that practically all cases of acute suppuration met with clinically are produced by the action of living micro-organisms.

Lesions in the Human Subject produced by Pyogenic Bacteria.

The following general statement may be made with regard to the occurrence of the chief organisms mentioned, in the various suppurative and inflammatory conditions in the human subject. It may also be noted that acute catarrhal conditions of cavities or tubes are in many cases also to be ascribed to their presence.

The *staphylococci* are the most common causal agents in

localised abscesses, in pustules on the skin, in carbuncles, boils, etc., in acute suppurative periostitis, in ulcerative endocarditis, and in various *pyæmic* conditions. They may also be present in septicæmia.

Streptococci are especially found in spreading inflammation with or without suppuration; in diffuse phlegmonous and erysipelatous conditions, suppurations in serous membranes and in joints (Fig. 45). They also occur in acute suppurative periostitis and ulcerative endocarditis. Secondary abscesses in lymphatic glands and in lymphangitis are also, we believe, more frequently caused by streptococci than staphylococci. They also produce fibrinous exudation on the mucous surfaces, leading to the formation of false membrane in many of the cases of non-diphtheritic inflammation of the throat, which are met with in scarlatina[1] and other conditions, and they are also the organisms most frequently present in acute catarrhal inflammations of this situation. In puerperal peritonitis they are frequently found in a condition of purity, and they also appear to be the most frequent cause of puerperal septicæmia, in which condition they may be found after death in the capillaries of various organs, though examination of the blood during life usually gives a negative result. In pyæmia they are frequently

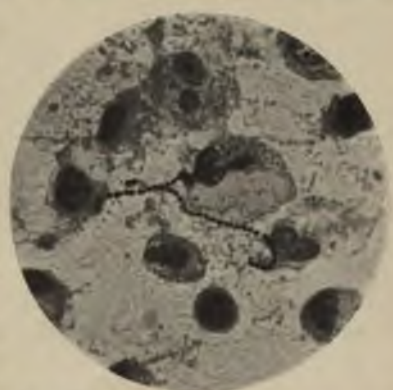

FIG. 45.—Streptococci in acute suppuration. Corrosive film; stained by Gram's method and safranin. × 1000.

[1] True diphtheria may also occasionally be associated with this disease, usually as a sequel.

present, though in most cases associated with other pyogenic organisms.

The *bacillus coli communis* is found in a great many inflammatory and suppurative conditions in connection with the alimentary tract, for example, in suppuration in the peritoneum or in the extraperitoneal tissue with or without perforation of the bowel, in the peritonitis following strangulation of the bowel, in appendicitis and the lesions following it, in suppuration around the bile ducts, etc. It may also occur in suppurations in other parts of the body, which in some cases are associated with lesions of the intestine, though in others such lesions cannot be found. It is also frequently present in inflammation of the urinary passages, cystitis, abscesses in the kidneys, etc.

The *micrococcus tetragenus* is often found in suppurations in the region of the mouth or in the neck, and also occurs in various lesions of the respiratory tract, in phthisical cavities, abscesses in the lungs, etc. Sometimes it is present alone, and probably has a pyogenic action in the human subject under certain conditions. In other cases it is associated with other organisms. Recently one or two cases of pyæmia have been described in which this organism was found in a state of purity in the pus in various situations. In this latter condition the pus has been described as possessing an oily viscous character, and as being often blood-stained.

The *bacillus pyocyaneus* is rarely found alone in pus, though it is not infrequent along with other organisms. We have met with it twice in cases of multiple abscesses, in association with the staphylococcus pyogenes aureus. Lately some diseases in children have been described in which the bacillus pyocyaneus has been found throughout the body; in these cases the chief symptoms have been fever, gastro-intestinal irritation, pustular or petechial eruptions on the skin, and general marasmus.

Suppurative conditions, associated with the organisms of special diseases, will be described in the respective chapters.

Mode of Entrance and Spread.—Many of the organisms of suppuration have a wide distribution in nature, and many also are present on the skin and mucous membranes of healthy individuals. Staphylococci are commonly present on the skin and also occur in the throat and other parts, and streptococci have a similar distribution and can very often be cultivated from the secretions of the mouth in normal conditions. The pneumococcus of Fraenkel and the pneumobacillus of Friedländer have also been found in the mouth and in the nasal cavity in normal conditions, whilst the bacillus coli communis is a normal inhabitant of the intestinal tract. The entrance of these organisms into the deeper tissues when a surface lesion occurs can be readily understood. Their action will, of course, be favoured by any depressed condition of vitality, though the conditions by which this takes place are not yet fully understood. Having gained entrance to the lymphatic spaces of the tissue they may spread by the lymphatic channels, or may gain entrance to the blood directly through the capillary walls. Though in normal conditions the blood is bacterium-free, we must suppose that from time to time a certain number of such organisms gain entrance to it from trifling lesions of the skin or mucous surfaces, the possibilities of entrance from the latter being especially numerous. In most cases they are killed by the action of the healthy serum or cells of the body, and no harm results. It may again be mentioned in this connection that it has been proved experimentally that, even in the case of a pathogenic organism, a considerable number can be destroyed in the blood of a healthy animal. If, however, there be a local weakness, they may settle in that part and produce suppuration, and thence other parts of the body may be infected. Such a supposition as this is necessary to explain many cases of suppuration met with clinically. Thus the liability of diseased heart-valves to become infected by organisms and thence to assume an ulcerative character, is well known. Conditions such as suppurative periostitis and osteomyelitis, multiple suppurative arthritis, suppurative

inflammations of several serous surfaces, and other similar conditions can be explained only in the same way. In some cases of multiple suppurations due to staphylococcus infection, which we have had the opportunity to examine, only an apparently unimportant surface lesion was present; whilst in others no lesion could be found to explain the

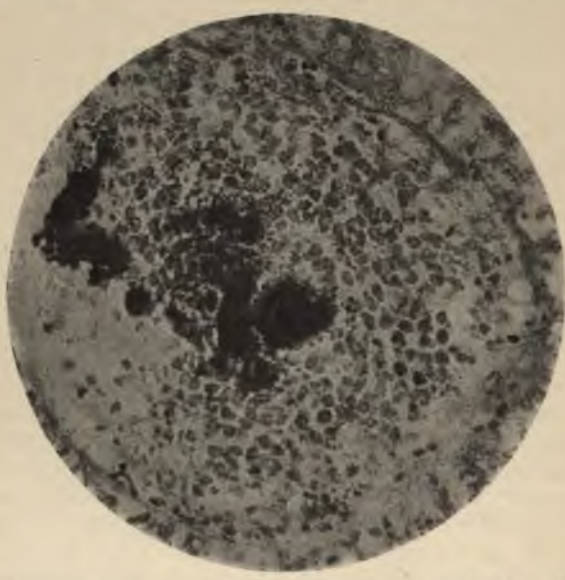

FIG. 46. — Secondary infection of a glomerulus of kidney by the staphylococcus aureus,[1] in a case of ulcerative endocarditis. The cocci (stained darkly) are seen plugging the capillaries and also lying free. The glomerulus is much swollen, infiltrated by leucocytes, and partly necrosed. Paraffin section; stained by Gram's method and Bismarck-brown. × 300.

origin of the infection. The organs or parts of the body affected vary much in different cases, the distribution being explicable only by selective action on the part of the organisms. In some cases the lungs are especially affected, in

[1] This organism was obtained in pure culture from the kidney.

others the kidneys (Fig. 46), in others the bones or joints, and so on. The term *cryptogenetic* has been applied by some writers to such cases in which the original point of infection cannot be found, but its use is scarcely necessary.

In cases of typical pyæmia originating from a septic wound, the infection of the blood usually takes place by the occurrence of a septic phlebitis of one of the adjacent veins with formation of a thrombus. The thrombus is invaded by the organisms, softens, and gives rise to emboli, which emboli, bearing the organisms with them, are arrested in the organs to which they are carried first, generally the lungs, and set up in them secondary abscesses which may reach a considerable size. Thence other organs may be affected in a corresponding manner. In such cases some of the pyogenic organisms mentioned, most frequently staphylococci and streptococci, are often associated with the organisms of putrefaction. Cases in which the organisms are carried in this way should be distinguished from those in which the organisms are free in the blood stream and settle in the parts specially susceptible, though in some instances both methods of infection may be present together.

The paths of secondary infection may be conveniently summarised thus: First, by lymphatics. In this way the lymphatic glands may be infected, and also serous sacs in relation to the organs where the primary lesion exists. Second, by natural channels, such as the ureters and the bile ducts, the spread being generally associated with an inflammatory condition of the lining epithelium. In this way the kidneys and liver respectively may be infected. Third, by the blood vessels: (*a*) by a few organisms gaining entrance to the blood from a local lesion, and settling in a favourable nidus or a damaged tissue, the original path of infection often being obscure; (*b*) by a septic phlebitis with suppurative softening of the thrombus and resulting embolism; and we may add (*c*) by a direct extension along a vein, producing a spreading thrombosis and suppuration within the vein. In this way suppuration may spread along the portal vein to the liver from a lesion in the alimentary

cess, the condition being known as *peri-pilethitis suppurativa*.

Some conditions produced by the pyogenic organisms demand special mention on account of their clinical importance, namely, ulcerative endocarditis, acute suppurative pyæmia and septicæmia, and erysipelas.

Ulcerative Endocarditis.—This condition has been proved to be a bacterial infection of the valves of the heart, and may be produced by various organisms, chiefly pyogenic. Of these the staphylococci and streptococci are most frequently found. In some cases of ulcerative endocarditis following pneumonia, the pneumococcus (Fraenkel's) is present; in others pyogenic cocci, especially streptococci. Other organisms have been cultivated from different cases of the disease, and some of these have received special names; for example, the diplococcus endocarditidis encapsulatus, bacillus endocarditidis grisea (Weichselbaum), and others. In some cases the bacillus coli communis has been found, and in a few cases following typhoid the typhoid bacillus has been described as the organism present, but further observations on this point are desirable. It has not yet been absolutely proved that the gonococcus affects the heart valves, though there are grounds for believing that it does so (p. 178). It has been described as being present in some cases, but so far as we know it has never been cultivated from this situation. Tubercle nodules on the heart valves have been found in a few cases of acute tuberculosis, though no vegetative or ulcerative condition is produced.

In some cases, though we believe not often, the organisms may attack healthy valves, producing a *primary* ulcerative endocarditis, but more frequently the valves have been the seat of previous endocarditis, *secondary* ulcerative endocarditis being thus produced. In both conditions the affection of the valves usually occurs in the course of suppurative or inflammatory conditions elsewhere, *e.g.*, in osteomyelitis, in septic inflammations of the urinary passages, in pyæmia and septicæmia, in the course of or following infective fevers, and not very infrequently as a sequel to acute

pneumonia. In some cases, especially when the valves have been previously diseased, the source of the infection is quite obscure. It is evident that as the vegetations are composed for the most part of unorganised material, they do not offer the same resistance to the growth of bacteria, when a few reach them, as a healthy cellular tissue does.

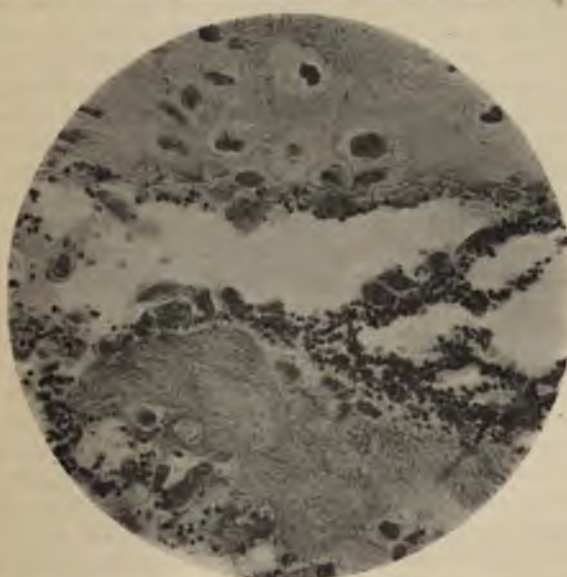

FIG. 47.—Section of a vegetation in ulcerative endocarditis, showing numerous staphylococci lying in the spaces. The lower portion is a fragment in process of separation.
Stained by Gram's method and Bismarck-brown. × 600.

On microscopic examination of the diseased valves the organisms are usually to be found in enormous numbers, sometimes forming an almost continuous layer on the surface, or occurring in large masses or clusters in spaces in the vegetation (Fig. 47). By their action a certain amount of softening or breaking down of the vegetations occurs,

and the emboli thus produced act as the carriers of infection to other organs, and give rise to secondary suppurations. The kidneys, heart-wall, brain, and spleen are most frequently infected in this way.

Experimental.—Occasionally ulcerative endocarditis is produced by the simple intravenous injection of staphylococci and streptococci into the circulation, but this is a very rare occurrence. It often follows, however, when the valves have been previously injured. Orth and Wyssokowitsch at a comparatively early date produced the condition by damaging the aortic cusps by a glass rod introduced through the carotid, and afterwards injecting staphylococci into the circulation. Similar experiments have since been repeated with streptococci, pneumococci and other organisms, with like result. Ribbert found that if a potato culture of the staphylococcus aureus were rubbed down so as to form an emulsion in salt solution, and then injected into the circulation, some minute fragments became arrested at the attachment of the chordæ tendineæ and produced an ulcerative endocarditis.

Acute Suppurative Periostitis and Osteomyelitis.—Special mention is made of this condition on account of its comparative frequency and gravity. Becker in 1883 described a coccus which he believed to be the special organism concerned in this disease, but it has been since completely proved that this organism is simply the staphylococcus pyogenes aureus. The great majority of cases are caused by the pyogenic cocci, of which one or two varieties may be present, the staphylococcus, however, occurring most frequently. Pneumococci have been found alone in some cases, and in a few cases following typhoid fever, apparently well authenticated, the typhoid bacillus has been found alone. In others again the bacillus coli communis is present.

The affection of the periosteum or interior of the bones by these organisms, which is specially common in young subjects, may take place in the course of other affections produced by these organisms or in the course of infective

fevers, but in a great many cases the path of entrance is quite obscure. That the organisms enter frequently by a small surface lesion, and are carried by the blood stream to the part affected, there can be no doubt. In the course of this disease they are always very liable to follow serious secondary infections, such as small abscesses in the kidneys, heart-wall, lungs, liver, suppurations in serous cavities, and ulcerative endocarditis; in fact, some cases present the most typical examples of extreme general staphylococcus infection. The entrance of the organisms into the blood stream from the lesion of the bone is especially favoured by the arrangement of the veins in the bone and marrow.

Experimental.—Multiple abscesses in the bone and under the periosteum may occur in simple intravenous injection of the pyogenic cocci into the blood, and are especially liable to be formed when young animals are used. These abscesses are of small size, and do not spread in the same way as in the natural disease in the human subject.

In experiments on healthy animals, however, the conditions are not analogous to those of the natural disease. We must presume that in the latter there is some local weakness or susceptibility which enables the few organisms which have reached the part by the blood to settle and multiply. If, however, a bone be injured, *e.g.*, by actual fracture or by stripping of the periosteum, before the organisms are injected, then a much more extensive suppuration occurs at the injured part.

Erysipelas.—A spreading inflammatory condition of the skin may be produced by a variety of organisms, but the disease in the human subject in its typical form is almost invariably due to a streptococcus, as was shown by Fehleisen in 1884. He obtained pure cultures of the organism, and gave it the name of streptococcus erysipelatis; and, further, by inoculations on the human subject as a therapeutic measure in malignant disease, he was able to reproduce erysipelas. As stated above, however, one after another of the supposed points of difference between the streptococcus of erysipelas and that of suppuration has broken down, and it

is now generally held that erysipelas is produced by the streptococcus pyogenes of a certain degree of virulence. It must be noted, however, that erysipelas passes from patient to patient as erysipelas, and purulent conditions due to streptococci do not appear liable to be followed by erysipelas. On the other hand, the connection between erysipelas and puerperal septicæmia is well established clinically. The conditions which produce the special degree of virulence in the streptococcus for the occurrence of erysipelas are not yet fully known.

In a case of erysipelas the streptococci are found in large numbers in the lymphatics of the cutis and underlying tissues, just beyond the swollen margin of the inflammatory area. As the inflammation advances they gradually die out, and after a time their extension at the periphery comes to an end. In the affected area there are the usual changes found in inflammation, great leucocytic emigration and serous exudation with formation of fibrin at places, but there is no suppurative liquefaction of the tissues. The streptococci may extend to serous and synovial cavities and set up inflammatory or suppurative change,—peritonitis, meningitis, and synovitis may thus be produced.

Methods of Examination for Pyogenic Bacteria.—These are usually of a comparatively simple nature, and include (1) microscopic examination, (2) the making of cultures.

(1) The pus or other fluids should be examined microscopically, first of all by means of film preparations in order to determine the characters of the organisms present. The films should be stained (*a*) by one of the ordinary solutions, such as carbol-thionin blue (p. 98), or a saturated watery solution of methylene-blue; and (*b*) by Gram's method. The use of the latter is of course of high importance as an aid in the recognition.

(2) As most of the pyogenic organisms grow readily on the gelatine media at ordinary temperatures, pure cultures can be readily obtained by the ordinary plate methods. But in many cases the separation can much more frequently be effected by the method of successive streaks on agar tubes

which are then incubated at 37° C. When the presence of pneumococci is suspected this method ought always to be used, and it is also to be preferred in the case of streptococci. Inoculation experiments may be carried out as occasion arises.

CHAPTER VII.

GONORRHŒA, SOFT SORE, SYPHILIS.

Gonorrhœa.

Introductory.—The micrococcus now known to be the cause of gonorrhœa, and often spoken of as the gonococcus, was first described by Neisser, who in 1879 gave an account of its microscopical characters as seen in the pus of gonorrhœal affections, both of the urethra and of the conjunctiva. He considered that this organism was peculiar to the disease, and that its characters were distinctive. The earlier announcements regarding pure cultures obtained on peptone-gelatine and other media, on which it does not really grow, are now known to be erroneous, but later it was successfully isolated and cultivated on solidified blood serum by Bumm and others. Its characters have since been minutely studied, and by inoculations of cultures on the human subject its causal relationship to the disease has been conclusively established.

The Gonococcus. — Microscopical Characters. — The organism of gonorrhœa is a small micrococcus which very often occurs in the diplococcus form, the adjacent margins of the two cocci being flattened, or even slightly concave, so that between there is a small oval interval which does not stain. An appearance is thus presented which has been compared to that of two beans placed side by side (*vide* Fig. 48). When division takes place in the two members of a diplo-

coccus, a tetrad is formed, which, however, soon separates into two sets of diplococci—that is to say, arrangement as diplococci is much commoner than as tetrads. Cocci in process of degeneration are seen as spherical elements of various size, some being considerably swollen; they lie singly or in small groups.

FIG. 48.—Portion of film of gonorrhœal pus, showing the characteristic arrangement of the gonococci within leucocytes. Stained with fuchsin. × 1000.

These organisms are found in large numbers in the pus of acute gonorrhœa, both in the male and female, and for the most part are contained within the leucocytes. In the earliest stage, when the secretion is glairy, a considerable number are lying free, or are adhering to the surface of desquamated epithelial cells, but when the discharge is purulent the large proportion within leucocytes is a very striking feature. In the leucocytes they lie within the protoplasm, especially superficially, and are often so numerous that the leucocytes appear to be filled with them, and their nuclei are obscured. As the disease becomes more chronic, the gonococci gradually become diminished in number, though even in long-standing cases they may still be found in considerable numbers. They are also present in the purulent secretion of gonorrhœal conjunctivitis, also in various parts of the female genital organs when these parts are the seat of true gonorrhœal infection, and they have been found in some cases in the secondary infections of the joints in the disease, as will be described below.

Staining.—The gonococcus stains readily and deeply

with a watery solution of any of the basic aniline dyes—methylene-blue, fuchsin, etc. It is, however, easily decolorised, and it completely loses the stain by Gram's method—an important point in the microscopical examination.

Cultivation of the Gonococcus.—This is attended with some difficulty, as the suitable media and conditions of growth are somewhat restricted. The most suitable media are solidified blood serum (especially human serum), "blood agar," and Wertheim's medium, which consists of one part of fluid serum, added to two parts of liquefied agar at a temperature of 40° C., and then allowed to solidify by cooling. The serum may be obtained from the blood of the human placenta; pleuritic or other effusion may also be used. Growth takes place best at the temperature of the body, and ceases altogether at 25° C. Cultures are obtained by taking some pus on the loop of the platinum needle and inoculating one of the media mentioned by leaving minute quantities here and there on the surface. The young colonies are visible within forty-eight hours, and often within twenty-four hours. They appear around the points of inoculation as small semi-transparent discs of irregularly rounded shape, the margin being undulated and sometimes showing small processes. The colonies vary somewhat in size and tend to remain more or less separate. They generally reach their maximum size on the fourth or fifth day, and are usually found to be dead on the ninth day, sometimes earlier. On the medium of Wertheim the period of active growth and the duration of life are somewhat longer. Even if impurities are present, pure sub-cultures can generally be obtained from the separate colonies of the gonococcus. In the early stage of the disease the organism is present in the male urethra in practically pure condition, and if the meatus of the urethra be sterilised by washing with weak solution of corrosive sublimate and then with absolute alcohol, and the material for inoculation be expressed from the deeper part of the urethra, cultures may often be obtained which are pure

from the first. By successive sub-cultures at short intervals, growth may be maintained indefinitely, and the organism gradually flourishes more luxuriantly. In culture the organisms have similar microscopic characters to those described (Fig. 49), but show a remarkable tendency to undergo degeneration, becoming swollen and of various sizes, and staining very irregularly. Degeneration forms are seen even on the second day, and in a culture four or five days old comparatively few normal cocci may be found. The less suitable the medium the more rapidly does degeneration take place.

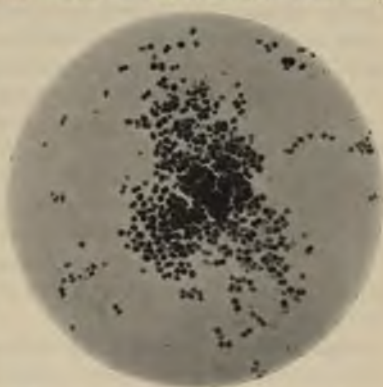

FIG. 49.—Gonococci, from a pure culture on blood agar of twenty-four hours' growth. Some already are beginning to show the swollen appearance common in older cultures. Stained with carbol-thionin-blue. × 1000.

On ordinary agar and on glycerine agar growth does not take place, or is so slight that these media are quite unsuitable for purposes of culture. The organism does not grow on gelatine,[1] potato, etc.

Plate-Cultures.—The following ingenious method of plate-culture was introduced by Wertheim for the culture of the gonococcus. The medium of culture is a mixture of human blood serum and of ordinary agar (2 per cent) in equal parts. The serum, in a fluid and sterile condition, is put in suitable quantities into two or three test tubes and brought to a temperature of 40° C. These are then

[1] Turro has announced that he has cultivated the gonococcus on acid gelatine, *i.e.*, ordinary peptone-gelatine which has not been neutralised. We have failed to obtain any growth of the gonococcus on this medium, even when inoculation was made from a vigorous growth on blood agar.

successively inoculated with the pus or other material in the same manner as gelatine tubes for ordinary plates (*vide* p. 59). To each tube is added an equal part of ordinary agar which has been thoroughly liquefied by heating and allowed to cool also to 40° C. The mixture is then thoroughly shaken up and quickly poured out on a plate or Petri's dish and allowed to solidify, the plates being then incubated at a temperature of 37° C. The colonies of the gonococcus are just visible in twenty-four hours, and are seen both in the substance of the medium and on the surface. The deep colonies when examined with a lens are minute and slightly nodulated spheres, sometimes showing little processes, whilst those on the surface are thin discs of larger diameter with wavy margin and rather darker centre. In this way the gonococcus may be separated from fluids which are contaminated with a considerable number of other organisms.

Relations to the Disease.—The gonococcus is invariably present in the urethral discharge in gonorrhœa, and also in other parts of the genital tract when these are the seat of true gonorrhœal infection. Its presence in these different positions has been demonstrated not only by microscopic examination but also by culture. From the description of the conditions of growth in culture, it will be seen that a life outside the body in natural conditions is practically impossible—a statement which corresponds with the clinical fact that the disease is always transmitted directly by contagion. Inoculations of pure cultures on the urethra of lower animals, and even of apes, is followed by no effect, but a similar statement can be made with regard to inoculations of gonorrhœal pus itself. In fact, hitherto it has been found impossible to reproduce the disease by any means in the lower animals. On a considerable number of occasions inoculations of pure cultures have been made on the human urethra, both of the male and female, and the disease, with all its characteristic symptoms, has resulted. (Such experiments have been performed independently by Bumm, Steinschneider, Wer-

theim, and others.) The causal relationship of the organism to the disease has therefore been completely established, and it is interesting to note how the conditions of growth and the pathogenic effects of the organism agree with the characters of the natural disease.

Intraperitoneal injections of pure cultures of the gonococcus in white mice produce a localised peritonitis with a small amount of suppuration, the organisms being found in large numbers in the leucocytes (Wertheim). They also penetrate the peritoneal lining and are found in the sub-endothelial connective tissue, but they appear to have little power of proliferation, they soon disappear, and the inflammatory condition does not spread. Injection of pure cultures into the joints of rabbits, dogs, and guinea-pigs causes an acute inflammation, which, however, soon subsides, whilst the gonococci rapidly die out. These experiments show that while the organism, when present in large numbers, can produce a certain amount of inflammatory change in these animals, it has little or no power of multiplying and spreading in their tissues.

Distribution in the Tissues.—The gonococcus having been thus shown to be the direct cause of the disease, some additional facts may be given regarding its presence both in the primary and secondary lesions. In the human urethra the gonococci penetrate the mucous membrane, passing chiefly between the epithelial cells, and cause a loosening and desquamation of many of the latter, and at the same time inflammatory reaction in the tissues below, attended with great increase of secretion. There occurs also a gradually increasing emigration of leucocytes which take up a large number of the organisms. It is to be noted, however, that though there is such an abundant phagocytosis, the cocci within the leucocytes are usually quite healthy in appearance, and the establishment of the phagocytosis is not followed by a rapid cure of the disease. The organisms also penetrate the subjacent connective tissue, and are especially found along with extensive leucocytic emigration around the lacunæ. Here also many are contained

within leucocytes. They are constantly being carried to the surface by leucocytes and discharged, but by multiplication they are able to maintain their footing till such a time as the disease comes naturally to an end. In acute gonorrhœa there is often a considerable degree of inflammatory affection of the prostate and vesiculæ seminales, but whether these conditions are due to the presence of gonococci in the affected parts we have not at present the data for determining. A similar statement also applies to the occurrence of orchitis and also of cystitis in the early stage of gonorrhœa. During the more chronic stages other organisms appear in the urethra, aid in maintaining the irritation, and may produce some of the secondary results. The bacillus coli, the pyogenic cocci, etc., are often present, and may extend along the urethra to the bladder and set up cystitis, though in this they may be aided by the passage of a catheter. It is then also that buboes usually occur, often associated with the presence of a small ulcer in the urethra. Though the bacteriology of these cannot yet be said to be fully worked out, they are certainly sometimes produced by the ordinary pyogenic organisms and by some varieties of diplococci which are often present in the urethra in abnormal conditions. It may be mentioned here that Wertheim cultivated the gonococcus from a case of chronic gonorrhœa of two years' standing, and by inoculation on the human subject proved it to be still virulent.

In the disease in the female, gonococci are almost invariably present in the urethra, the situation affected next in frequency being the cervix uteri. They do not appear to infect the lining epithelium of the vagina of the adult unless some other abnormal condition be present, but they do so in the gonorrhœal vulvo-vaginitis of young subjects. They have also been found in suppurations in connection with Bartholini's glands, and sometimes produce an inflammatory condition of the mucous membrane of the body of the uterus. They may also pass along the Fallopian tubes and produce inflammation of the mucous membrane there. From the pus in cases of pyosalpinx they have been culti-

vated in a considerable number of cases. According to the results of various observers they are present in one out of four or five cases of this condition, usually unassociated with other organisms. Lastly, they may pass to the peritoneum and produce peritonitis, which is usually of a local character. It is chiefly to the methods of culture supplied by Wertheim that we owe our extended knowledge of such conditions.

Relations to Joint Affections, etc.—The relations of the gonococcus to the sequels of gonorrhœa form a subject of great interest and importance, but one which cannot be said to be yet fully worked out. The reason of this is that till within the last few years the cultivation of the gonococcus had been a matter of considerable difficulty, and without cultures it is not possible to be absolutely certain of the identity of the organism, especially when present only in small numbers, there being other species of diplococci, some of which have been cultivated from the urethra in normal and diseased conditions, and which resemble the gonococcus not only in microscopical characters, but also in staining reaction. At present, however, the following statements may be made. First, in a certain number of cases of arthritis following gonorrhœa the gonococcus has been found microscopically, and pure cultures have been obtained, *e.g.*, by Neisser, Lang, Bordoni-Uffreduzzi, and others. A similar statement applies to inflammation of the sheaths of tendons following gonorrhœa. Secondly, in a large proportion of cases no organisms have been found. Thirdly, in some cases, especially in those associated with extensive suppuration, occasionally of a pyæmic nature, various pyogenic cocci have been found to be present. It must therefore be considered that a secondary infection of the joints by the gonococcus, evidently by way of the blood stream, can occur, and it remains to be determined in what proportion of cases it does so. In the instances in which the gonococcus has been found in the joints, the fluid present has been described as being usually of a whitish-yellow tint, turbid in appearance, and containing shreds of fibrin-like material, sometimes purulent in appearance. It has also

been noted in one or two cases, where the surface of the synovial membrane has been carefully examined, that the gonococci have been much more numerous there than in the fluid—a circumstance which may explain some of the negative results when the fluid alone is examined. In one case Bordoni-Uffreduzzi cultivated the gonococcus from a joint-affection, and afterwards produced gonorrhœa in the human subject by inoculating with the cultures obtained. In another case in which pleurisy was present along with arthritis the gonococcus was cultivated from the fluid in the pleural cavity. The existence of a gonorrhœal endocarditis has not yet been absolutely proved by means of cultures, though cases such as those described by Leyden and Michaelis are probably of this nature. In these cases organisms were present in the vegetations which, in their position within leucocytes, in their microscopical characters, and in their staining reactions, corresponded to gonococci. Cultures of the gonococcus were not obtained, but no growth of any organism took place on the media used, a circumstance which is in favour of the view that the organisms present were really gonococci.

Methods of Diagnosis.—For microscopical examination dried films of the suspected pus, etc., may be stained by any of the simple solutions of the basic aniline stains. We prefer methylene- or thionin-blue, as they do not overstain, and the films do not need to be decolorised. Staining for one minute is sufficient. It is also advisable to stain by Gram's method, and it is a good plan to put at one margin of the cover-glass a small quantity of culture of staphylococcus aureus if available, in order to have a standard by which to be certain that the supposed gonococci are really decolorised. Regarding the value of microscopic examination alone, we may say that the presence of a large number of micrococci in a urethral discharge having the characters, position, and staining reactions described above, is practically conclusive that the case is one of gonorrhœa. There is no other condition in which the sum total of the microscopical characters is present. We consider that it is

sufficient for purposes of clinical diagnosis, and therefore of great value; in the acute stage a diagnosis can thus be made earlier than by any other method. The mistake of confusing gonorrhœa with such conditions as a urethral chancre with urethritis, will also be avoided. Even in chronic cases the typical picture is often well maintained, and microscopic examination alone gives a definite positive result. When other organisms are present, and especially when the gonococci are few in number, it is difficult, and in many cases impossible, to give a definite opinion, as a few gonococci mixed with other organisms cannot be recognised with certainty. This is often the condition in chronic gonorrhœa in the female. Microscopic examination, therefore, though often giving positive results, will sometimes be inconclusive. Cultures alone supply the absolute test, and when the organism is present in an apparent condition of purity, Wertheim's medium or blood-agar should be used. If other organisms are present, we are practically restricted to Wertheim's plate method.

Soft Sore.

Within recent years a considerable amount of attention has been directed to the bacteriology of this condition, owing to the discovery of a somewhat characteristic bacillus in the affected parts. This organism was first described by Ducrey in 1889, who found it in the purulent discharge from the ulcerated surface; and later, in 1892, Unna described its appearance and distribution as seen in sections through the sores. The statements of these observers regarding the presence and characters of this organism have been fully confirmed by other observers.

Microscopical Characters.—This organism occurs in the form of minute oval rods measuring about 1.5 μ in length, and .5 μ in thickness. It is found mixed with other organisms in the purulent discharge from the surface, and is chiefly arranged in small groups or in short chains.

When studied in sections through the ulcer it is found in the superficial part of the floor, but more deeply situated than other organisms, and may be present in a state of purity amongst the leucocytic infiltration. In this position it is usually arranged in chains which may be of considerable length, and which are often seen lying in parallel rows between the cells. Both in the tissues and in the secretions the bacilli chiefly occur in the free condition, but occasionally a few may be contained within leucocytes.

This bacillus takes up the basic aniline stains fairly readily, but loses the colour very rapidly when a decolorising agent is applied. Accordingly, in film preparations when dehydration is not required, it can be readily stained by most of the ordinary combinations, though Löffler's or Kühne's methylene-blue solutions are preferable, as they do not overstain. In sections, however, great care must be taken in the process of dehydration, and the aniline-oil method (*vide* p. 96) should be used for this purpose, as alcohol decolorises the organism very readily. A little of the methylene-blue or other stain may be with advantage added to the aniline oil used for dehydrating.

This organism has not yet been successfully cultivated outside the body, though practically every medium has been tried for this purpose. Ducrey, however, succeeded in separating it from other organisms by the following method. He produced a series of pustules by successive inoculations in the human subject on the skin, which had been previously sterilised, the pustules being afterwards protected from contamination by watch-glasses fixed in position. He found that in this method the other organisms gradually died off, while the characteristic bacilli persisted, and at about the fifth or sixth inoculation might be present alone. Further, the pus containing the bacilli in a pure condition still produced the typical lesion on inoculation. Even when the organisms were thus separated he failed to obtain any growth on the numerous media which he employed.

The evidence that this organism is the causal agent in

the affection accordingly rests on the facts well established that the organism is apparently always present in the discharge from the sore, and in its tissues; that it has been observed hitherto in no other form of ulceration, and that it is sharply marked off from saprophytic organisms by the fact that it has not been obtained in cultures outside the body.

Regarding the presence of this organism in the buboes associated with soft sore there is some uncertainty. A considerable number of observers have failed to find it, and have also failed to produce a characteristic soft sore by inoculation with pus withdrawn from a bubo under aseptic precautions. When a chancroid condition follows in a bubo which has been opened, they accordingly consider that it has been secondarily inoculated with the bacillus. On the other hand one or two observers have found the bacillus in unopened buboes. Audry, for example, found it in a bubo before it had suppurated, lying in little groups of two or three within leucocytes in the lymph channels; and in this case inoculation with the material from the bubo produced the typical lesion. Krefting also found it in buboes in some cases. It is therefore possible that the buboes associated with soft sore are caused by the same organisms, but that as suppuration occurs they in great part die off. It seems certain at least, from the results of various workers, that in many cases the ordinary pyogenic organisms are not present in the suppurating buboes.

In connection with the two diseases, gonorrhœa and soft sore, it is of special interest to note in the case of the former how restricted are the conditions of growth outside the body of the organism which produces the disease, and that in the case of the latter, on the supposition that the organism described above is the causal agent, attempts to cultivate it outside the body have entirely failed.

Syphilis.

Regarding the relation of bacteria to this disease, we cannot be said at present to possess much definite knowledge. Most interest, however, is attached to the observations of Lustgarten, who in 1884 described a characteristic bacillus both in the primary sore and in the lesions in internal organs. He found it in all of sixteen cases which he examined. This bacillus somewhat resembles the tubercle bacillus in shape and size. It occurs in the form of slender rods, straight or slightly bent, about 3 to 4 μ in length, often forming little clusters either within cells or lying free in the lymphatic spaces. Like the tubercle bacillus it takes up the basic aniline stains with difficulty, but it is much more easily decolorised by mineral acids. Lustgarten stained the tissues for twenty-four to forty-eight hours in aniline-water solution of gentian violet; and then, after washing them in alcohol, placed them for ten seconds in a 1.5 per cent solution of permanganate of potassium. They were then treated with sulphurous acid, which removes the brown precipitate formed, and decolorises the sections. They were then washed in water, dehydrated, and mounted. The observations of other workers have given contradictory results. De Michele and Radice, for example, found Lustgarten's bacilli in the tissues in forty-five out of sixty-four cases examined, while, on the other hand, other observers have failed to find them.

Apart, however, from negative results obtained by many, criticism has been made in other ways. It has been alleged by some that Lustgarten's bacillus is merely the *smegma bacillus* which has penetrated the affected tissues. This bacillus, which was first described by Alvarez and Tavel, occurs in the *smegma preputiale*, and morphologically resembles somewhat the tubercle bacillus, but is more easily decolorised. The above explanation, however, would not account for the presence of the bacilli in the internal organs, where they were observed by Lustgarten

and others. And further, there are minor points of difference between this smegma bacillus and Lustgarten's bacillus. It has also been suggested by some that the organisms described by Lustgarten are merely tubercle bacilli which have been accidentally present in the affected tissues. Those, however, who have found the former organism in the tissues agree that it can be readily distinguished from tubercle bacillus, as it does not resist decolorising with strong acids. This explanation of the presence of these bacilli in the tissues is really without definite support.

The organism has not been cultivated outside the body, though, in view of what we know with regard to some other diseases, this fact in itself does not form a grave objection. In the absence, however, of definite evidence as to its invariable presence in the lesions, its relations to the disease are still highly problematical. It may also be noticed that this organism has been found in the tertiary lesions, which are usually believed to be non-infectious.

CHAPTER VIII.

ACUTE PNEUMONIA.

Introductory.—Pneumonia, as a clinical term, is applied to several conditions which present differences in pathological anatomy and in origin. There is, first of all, the acute croupous or lobar pneumonia, in which an inflammatory process attended by abundant fibrinous exudation affects, by continuity, the entire tissue of a lobe or of a large portion of the lung. This type is, both in its clinical symptoms and pathological effects, familiar. Secondly, there is the acute catarrhal or lobular pneumonia, where the inflammatory process spreads from the capillary bronchi to the air-vesicles, and leads to a catarrhal consolidation of patches of the lung tissue. Up till 1889 acute catarrhal pneumonia was comparatively rare except in children. In adults it was chiefly found as a secondary complication to some condition such as diphtheria, typhoid fever, etc. Since the first recent great epidemic of influenza in the year named, however, it has been of much more frequent occurrence in adults, has assumed a very fatal tendency, and has presented the formerly quite unusual feature of being sometimes the precursor of gangrene of the lung. Moreover, not only has the prevalent type of pneumonia (the term being used in its widest sense) changed through the occurrence of a greater proportion of catarrhal cases, but it appears to be now more common to find cases which microscopically present a mixed type, *i.e.*, in

which both an acute croupous condition and an acute catarrh occur in the same lung.

Besides these two clinical types of pneumonia there is another group of cases which are somewhat loosely denominated septic pneumonias, and which may arise in two ways: (1) by the entrance into the trachea and bronchi of discharges, blood, etc., which form a nidus for the growth of septic organisms, and thus infect the tissue of the lung; (2) from secondary pyogenic infection by means of the blood stream from suppurative foci in other parts of the body. (See Chapter on Suppuration, etc.)

We shall see that bacteria have been found associated with all these types of pneumonia. Special importance is attached to acute croupous pneumonia on account of its course and characters, but reference will also be made to the other forms.

Historical.—Acute lobar pneumonia for long, both popularly and medically, had been supposed to be an effect of exposure to cold; but there were not wanting those who were dissatisfied with this view of its etiology. Not only did many cases occur where no such exposure could be traced, but it had been observed that the disease sometimes occurred epidemically, and was occasionally contracted by hospital patients lying in beds adjacent to those occupied by pneumonia cases. Further, the sudden onset and definite course of the disease conformed to the type of an acute infective fever. It was thus suspected by some that it might in reality be due to a specific infection. After the commencement of bacteriological investigation, various observers described the occurrence of micro-organisms in the lungs or other organs of persons dead of the disease. The first real contributor, however, to the modern view of its etiology was Friedländer. In 1882 and 1883 this author published several papers giving the result of his researches. Briefly, these results were as follows. In the bronchial contents and in sections of pneumonic lungs, there were organisms which he described as cocci, adherent usually in pairs, and which possessed a

definitely contoured capsule which was faintly but distinctly stained. These cocci could be isolated and grown on gelatine, and they assumed in stab cultures on gelatine a very characteristic appearance. On inoculation in mice they produced definite pathogenic effects. Instead of developing pneumonia, however, the animals died of a kind of septicæmia with inflammation of the serous membranes. The blood and the exudation in serous cavities contained numerous capsulated diplococci. Though of course this was not proof that the cocci were the cause of the disease in man, Friedländer brought forward the growing tendency to regard pneumonia as an infectious disease, the alleged universal occurrence of his cocci in the lungs of persons dead of the disease, and the pathogenic capacities of these cocci in animals, as indications that an etiological factor had been discovered. Various criticisms of Friedländer's views soon appeared, and there is little doubt that many of the organisms seen by Friedländer were really Fraenkel's pneumococcus to be presently described.

By many observers it was found that the sputum of healthy men, when injected into animals, sometimes caused death, with the same symptoms as in the case of the injection of Friedländer's coccus; and in the blood and serous exudations of such animals capsulated cocci were found. A. Fraenkel investigated this subject, and found that the sputum of pneumonic patients was much more fatal and more constant in its effects than that of healthy individuals. The cocci which were found in animals dead of this "sputum septicæmia" as it was called, differed from Friedländer's cocci in not growing at the ordinary temperature. They required to be incubated at higher temperatures, and on sloped agar gave a very thin greyish film of growth. They also differed in shape from Friedländer's cocci, being somewhat oval and pointed at their free extremities. Fraenkel further investigated a few cases of pneumonia, and isolated from them cocci identical in microscopic appearances, cultures, and pathogenic effects, with

those isolated in sputum septicæmia. Mice, guinea-pigs, and rabbits were susceptible to them. (In one of his cases Fraenkel observed Friedländer's coccus.) Similar cocci were observed by Talamon and others, but the most extensive investigations on the whole question were those of Weichselbaum, published in 1886. This author examined 129 cases of the disease, and included in this survey not only acute croupous pneumonia, but lobular, hypostatic, and septic pneumonias. From them he isolated four groups of organisms. (1) *Diplococcus pneumoniæ.* This he described as an oval or lancet-formed coccus, occurring in pairs or in straight chains containing four to eight individuals. It corresponded in appearance and growth characters to Fraenkel's coccus. (2) *Streptococcus pneumoniæ.* This was less common than the last, was rounder, and formed longer and more twisted chains, but on the whole presented similar characters. It was more vigorous in its growth, and could grow below 20° C., though it preferred a temperature of 37° C. (3) *Staphylococcus pyogenes aureus.* (4) *Bacillus pneumoniæ.* This was a short rod-shaped organism which must be classed among the bacilli. Weichselbaum, however, was of opinion that it was identical with Friedländer's pneumococcus.

Of these organisms the diplococcus pneumoniæ was by far the most frequent, being observed in 94 cases of the 129 examined, and isolated by cultures in 54. It also occurred in all forms of pneumonia. Next in frequency was the streptococcus pneumoniæ, and lastly the bacillus pneumoniæ. Inoculation experiments were also performed by Weichselbaum with each of the three characteristic cocci he isolated. The diplococcus pneumoniæ and the streptococcus pneumoniæ both gave pathogenic effects of a similar kind in certain animals.

The general result of these earlier observations was to establish the occurrence in connection with pneumonia of two species of organisms, each having its distinctive characters, viz. :—

1. *Fraenkel's pneumococcus*, which is recognised to be

identical with the coccus of "sputum septicæmia," with Weichselbaum's diplococcus pneumoniæ, and probably also with his streptococcus pneumoniæ.

2. *Friedländer's pneumococcus* (now known as Friedländer's pneumobacillus), which is almost certainly the same as the bacillus pneumoniæ of Weichselbaum.

The way is thus opened for our describing more in detail the morphological characters of these two organisms prior to considering the evidence for their etiological relationship to the disease with which they are found associated. We shall use the terms "Fraenkel's pneumococcus" and "Friedländer's pneumobacillus," as these are now usually applied to the two organisms.

Microscopic Characters of the Bacteria of Pneumonia.—*Methods.*—The organisms present in acute pneumonia can best be examined in film preparations made from pneumonic lung (preferably from a part in a stage of acute congestion or early hepatization) or from the gelatinous parts of pneumonic sputum (here again preferably when such sputum is either rusty or occurs early in the disease), or in sections of pneumonic lung. Such preparations may be stained by any of the ordinary weak stains, such as a watery solution of methylene-blue, but Gram's method is to be preferred, with safranin or Bismarck-brown as a contrast stain. Ziehl-Neelsen carbol-fuchsin is also very suitable; it is best either to stain with it for only a few seconds, or to overstain and then decolorise with alcohol till the ground of the preparation is just tinted. In such preparations as the above, and even in specimens taken from the lungs immediately after death (as may be quite well done by means of a hypodermic syringe), putrefactive and other bacteria may be present, but those to be looked for are capsulated organisms which may be of either or both of the varieties mentioned.

(1) *Fraenkel's Pneumococcus.*—This organism occurs in the form of small oval cocci, about 1 μ in longest diameter, arranged generally in pairs (diplococci), but also in chains of four to ten (Fig. 50). The free ends are often pointed like a lancet, hence the term *diplococcus lanceolatus* has also

been applied to it. These cocci have round them a capsule, which usually appears as an unstained halo, but is sometimes stained more deeply than the ground of the preparation. This difference in staining depends, in part at least, on the amount of decolorisation to which the preparation has been subjected. The capsule is rather broader than the body of the coccus, and has a sharply defined external margin. This organism takes up the basic aniline stains with great readiness, and also *retains the stain in Gram's method.* It is the organism of by far the most frequent occurrence in true croupous pneumonia, and in fact may be said to be rarely absent.

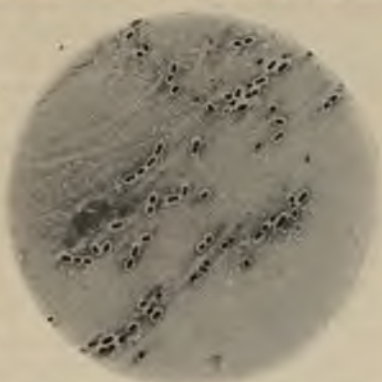

FIG. 50.—Film preparation of pneumonic sputum, showing numerous pneumococci (Fraenkel's) with capsules; some are arranged in short chains.
Stained with carbol-fuchsin. × 1000.

(2) *Friedländer's Pneumobacillus.*—As seen in the sputum and tissues, this organism both in its appearance and arrangement, as also in the presence of a capsule, somewhat resembles Fraenkel's pneumococcus, and it was at first described as the "pneumococcus." The form, however, is more of a short rod-shape, and it has blunt rounded ends; it is also rather broader than Fraenkel's pneumococcus. It is now usually classed amongst the bacilli, especially in view of the fact that in cultures elongated rod forms may occur. The capsule has the same general characters as that of Fraenkel's organism. Friedländer's pneumobacillus stains readily with the basic aniline stains, but *loses the stain in Gram's method*, and is accordingly coloured with the contrast stain,—safranin or Bismarck-brown, as above

recommended. A valuable means is thus afforded of distinguishing it from Fraenkel's pneumococcus in microscopic preparations.

Friedländer's organism is much less frequently present in pneumonia than Fraenkel's; sometimes it is associated with the latter, rarely it occurs alone.

In sputum preparations the capsule of both pneumococci may not be recognisable, and the same is sometimes true of lung preparations. This is probably due to changes which occur in the capsule as the result of changes in the vitality of the organisms. Sometimes the difficulty of recognising the capsule when it is present, is due to the refractive index of the fluid in which the specimen is mounted being almost identical with that of the capsule. This difficulty can always be overcome by having the ground-work of the preparation tinted.

The Cultivation of Fraenkel's Pneumococcus.—It is usually difficult, and sometimes impossible, to isolate this coccus directly from pneumonic sputum. On culture media it has not a vigorous growth, and when mixed with other bacteria it is apt to be overgrown by the latter. To get a pure culture it is best to insert a small piece of the sputum beneath the skin of a rabbit or a mouse. In about forty-eight hours the animal will die, with its blood containing capsulated pneumococci. From the heart-blood, cultures of these can be easily obtained. Cultures can also be got *post mortem* from the lungs of pneumonic patients. Here it is best to streak a number of agar or blood-agar tubes with a scraping taken from the area of acute congestion or commencing red hepatization, and incubate them at 37° C. The colonies of the pneumococcus appear as almost transparent small discs which have been compared to drops of dew. This method is also sometimes successful in the case of sputum.

The pneumococcus grows best on blood serum or on Pfeiffer's blood-agar. It also grows well on ordinary agar or in bouillon or on gelatine (incubated at 22° C.), but not so well on glycerine agar. In a stroke culture on *blood*

serum growth appears as an almost transparent pellicle along the track, with isolated colonies at the margin. On *agar* media it is more manifest, but otherwise has similar characters (Fig. 51). The appearances are similar to those of a culture of streptococcus pyogenes, but the growth is less vigorous, and is more delicate in appearance. A similar statement also applies to cultures in *gelatine*, growth in a stab culture appearing as a row of minute points which remain of small size; there is, of course, no liquefaction of the medium. On agar plates colonies are almost invisible to the naked eye, but under a low power of the microscope appear to have a compact finely granular centre and a pale transparent periphery. In *bouillon*, growth forms a slight turbidity, which settles to the bottom of the vessel as a slight dust-like deposit. On *potatoes*, as a rule, no growth appears. Cultures on such media may be maintained for one or two months, if fresh sub-cultures are made every four or five days, but they tend ultimately to die out. They also rapidly lose their virulence, so that four or five days after isolation from an animal's body their pathogenic action is already diminished. In none of the ordinary artificial media does the pneumococcus develop a capsule. (Guarnieri grew the pneumococci on the following medium: meat infusion 950 c.c., NaCl 5 grm., peptone 25 grm., gelatine 40 grm., agar 3 per cent, water 50 c.c. This medium at 37° C. is semi-solid, and in it Guarnieri states the cocci developed capsules.) They usually appear as diplococci, but in preparations made from the surface of agar or from bouillon, shorter or longer chains may be observed

FIG. 51. — Stroke culture of Fraenkel's pneumococcus on agar, showing a faint streak with small semi-transparent colonies; two days' growth at 37° C. Natural size.

(Fig. 52). After a few days' growth they lose their regular shape and size, and involution forms appear. Unless when very unusually vigorous the pneumococcus does not grow below 22° C. Its optimum temperature is 37° C., its maximum 42° C. It is preferably an aërobe, but can exist without oxygen. It prefers an alkaline medium to a neutral, and does not grow on an acid medium. These facts show that when growing outside the body on artificial media, the pneumococcus is a comparatively delicate organism.

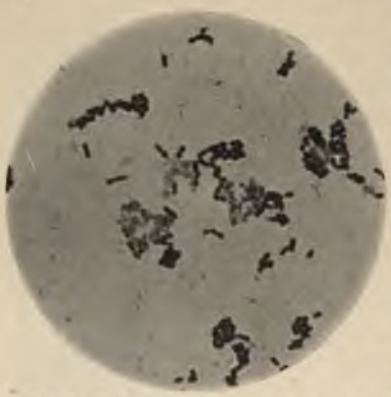

FIG. 52.—Fraenkel's pneumococcus from a pure culture on blood agar of twenty-four hours' growth, some in pairs, some in short chains. Stained with weak carbol-fuchsin. × 1000.

The Cultivation of Friedländer's Pneumobacillus.—This organism, when present in sputum or in a pneumonic lung, can be readily separated by making ordinary gelatine plate cultures, or a series of successive strokes on agar tubes. The surface colonies always appear as white discs which become raised from the surface so as to appear like little knobs of ivory. From these, pure cultures can be readily obtained. The appearance of a stab culture in gelatine growth is very characteristic. At the site of the puncture, there is on the surface a white growth heaped up, it may be fully one-eighth of an inch above the level of the gelatine; along the needle track there is a white granular appearance, so that the whole resembles a white round-headed nail driven into the gelatine (Fig. 53). Hence the name 'nail-like' which has been applied. Occasionally bubbles of gas develop along the line of growth. There is no liquefaction of the medium. On sloped *agar* it forms a very white growth

with a shiny lustre, which, when touched with a platinum needle, is found to be of a viscous consistence. In

FIG. 53. — Stab culture of Friedländer's pneumobacillus in peptone gelatine, showing the nail-like appearance; six days' growth. Natural size.

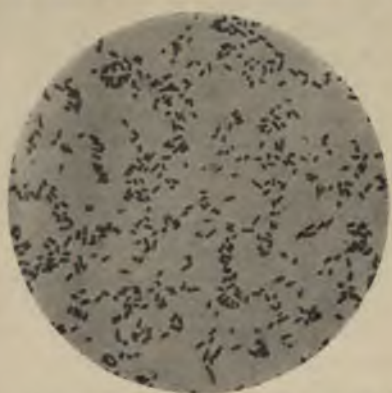

FIG. 54. — Friedländer's pneumobacillus,[1] from a young culture on agar; showing some rod-shaped forms.
Stained with thionin-blue. × 1000.

cultures much longer rods are formed than in the tissues of the body (Fig. 54). On the surface of *potatoes* it forms an abundant moist white layer. Friedländer's bacillus has active fermenting powers on sugars, though varieties isolated by different observers vary in the degree in which such powers are possessed. It always seems capable of acting on dextrose, lactose, maltose, dextrin, and mannite, and sometimes also on glycerine. The substances produced by the fermentation vary with the sugar fermented, but include ethylic alcohol, acetic acid, lævolactic acid, succinic acid, along with hydrogen and carbonic acid gas.

[1] The apparent size of this organism, on account of the nature of its sheath, varies much according to the stain used. If stained with a strong stain, *e.g.*, carbol-fuchsin, its thickness appears nearly twice as great as is shown in the figure.

The amount of acid produced from lactose seems only exceptionally sufficient to cause coagulation of milk.

The Occurrence of the Pneumobacteria in Pneumonia and other Conditions. — The pathological anatomy of pneumonia is so fully dealt with in all text-books on pathology, that it is unnecessary for us to do more than emphasise its strictly bacteriological features. Capsulated organisms have been found in every variety of the disease — in acute croupous pneumonia, in broncho-pneumonia, in septic pneumonia. In the great majority of these it is Fraenkel's pneumococcus which both microscopically and culturally has been found to be present. Friedländer's pneumobacillus occurs in only about 5 per cent of the cases. It may be present alone or associated with Fraenkel's organism. In a case of croupous pneumonia the pneumococci are found all through the affected area in the lung, especially in the exudation in the air-cells. They also occur in the pleural exudation and effusion, and in the lymphatics of the lung. The greatest number are found in the parts where the inflammatory process is youngest, *e.g.*, in an area of acute congestion in a case of croupous pneumonia, and therefore such parts are preferably to be selected for microscopic examination, and as the source of cultures. Sometimes there occur in pneumonic consolidation, areas of suppurative softening in the lung, which lead to destruction of, it may be, considerable areas of lung tissue. In such areas of softening the pneumococci occur with or without ordinary pyogenic organisms, streptococci being the commonest concomitants. There may occur in pneumonia, especially when the condition is secondary to influenza, gangrenous areas which may by a process of colliquative necrosis lead to destruction of large portions of the lung. In these a great variety of bacteria, both aërobes and anærobes, are to be found.

In ordinary acute croupous pneumonia it is usually, as we have seen, Fraenkel's pneumococcus which occurs. In ordinary broncho-pneumonias also it is usually present,

sometimes along with pyogenic cocci; but in the broncho-pneumonias secondary to diphtheria it may be accompanied by the diphtheria bacillus, and also by the ordinary pyogenic cocci; in typhoid pneumonias the typhoid bacillus or the B. coli may be also present, and in influenza pneumonias the influenza bacillus. In septic pneumonias it may occur associated with pyogenic cocci, but the latter in many cases are the only organisms discoverable. Especially important, as we shall see, from the point of view of the etiology of the disease, is the occurrence in other parts of the body of pathological conditions associated with the presence of the pneumococcus. By direct extension to neighbouring parts empyema, pericarditis, and lymphatic enlargements in the mediastinum and neck may take place; in the first the pneumococcus may occur either alone or with pyogenic cocci. But distant parts may be affected, and the pneumococcus may be found in suppurations and inflammations in various parts of the body (subcutaneous tissue, joints, kidneys, liver, etc.), in otitis media, ulcerative endocarditis (p. 164), and meningitis. These conditions may take place either as complications of pneumonia, or they may constitute the primary disease. The occurrence of meningitis is of special importance, for next to the lungs the meninges appear to be the parts most liable to attack by the pneumococcus. A large number of cases have been investigated by Netter, who gives the following tables of the relative frequency of the primary infections by the pneumococcus in man:—

(1) In adults—

Pneumonia	65.95 per cent.
Broncho-pneumonia / Capillary bronchitis	15.85 ,,
Meningitis	13.00 ,,
Empyema	8.53 ,,
Otitis	2.44 ,,
Endocarditis	1.22 ,,
Liver abscess	1.22 ,,

(2) In children 46 cases were investigated. In 29 the primary affection was otitis media, in 12 broncho-pneumonia, in 2 meningitis, in 1 pneumonia, in 1 pleurisy, in 1 pericarditis.

Thus in children the primary source of infection is in a great many cases an otitis media, and Netter concludes that infection takes place in such conditions from the nasal cavities.

Experimental Inoculation.—Having thus seen that there are present in the pneumonic processes and their complications certain organisms which possess distinct morphological and biological characters, and of which by far the most frequently present is Fraenkel's pneumococcus, we have now to consider the evidence for their etiological relationship to the disease.

The *pneumococcus* of Fraenkel is pathogenic to various animals. The susceptibility of different species varies to a considerable extent. This point has been fully worked out by Gamaleia. The rabbit, and especially the mouse, are very susceptible; the guinea-pig, the rat, the dog, and the sheep, occupy an intermediate position; the pigeon is quite immune. In the more susceptible animals the general type of the disease produced is not pneumonia, but a general *septicæmia*. Thus, if a rabbit or a mouse be injected subcutaneously with pneumonic sputum, or with a scraping from a pneumonic lung, death occurs in from twenty-four to forty-eight hours. There is some fibrinous infiltration at the point of inoculation, the spleen is often enlarged and firm, and the blood contains capsulated pneumococci in large numbers (Fig. 55). If the seat of inoculation be in the lung, there generally results pleuritic effusion on both sides, and in the lung there may be a process resembling in pathological characters the early stage of acute croupous pneumonia in man. There are often also pericarditis and enlargement of spleen. We have already stated that cultures of the pneumococci on artificial media in a few days begin to lose their virulence. Now, if such a partly attenuated culture be injected subcutaneously into a rabbit, there is greater local reaction, and pneumonia, with exudation of lymph on the surface of the pleura, and a similar condition in the peritoneum, may occur. In the rat the results of inoculation are closely similar, and its

relatively lower susceptibility is only marked by the fatal dose being larger. In sheep, however, greater immunity is marked by the occurrence, after subcutaneous inoculation, of an enormous local sero-fibrinous exudation, and by the fact that few pneumococci are found in the blood stream. Intra-pulmonary injection in sheep is followed by a typical

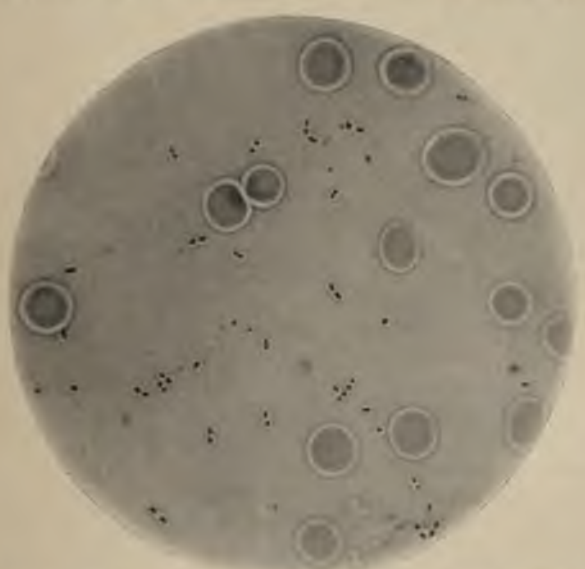

FIG. 55.—Capsulated pneumococci in blood taken from the heart of a rabbit, dead after inoculation with pneumonic sputum.

Dried film, fixed with corrosive sublimate. Stained with carbol-fuchsin and partly decolorised. × 1000.

pneumonia, which is generally fatal. The dog is still more immune, but in it also intra-pulmonary injection is followed by a fibrinous pneumonia, which is only sometimes fatal. Inoculation by inhalation appears only to have been performed in the susceptible mouse and rabbit, and the effects were similar to those of subcutaneous injection.

The general conclusion to be drawn from these experiments thus is that in highly susceptible animals virulent pneumococci produce a general septicæmia, whereas in more immune species there is an acute local reaction at the point of inoculation, and if the latter be in the lung, then there may result pneumonia, which, of course, is merely a local acute inflammation occurring in a special tissue, but identical in essential pathology with an inflammatory reaction in any other part of the body. When a dose of pneumococci sufficient to kill a rabbit is injected subcutaneously in the human subject, it gives rise to a local inflammatory swelling, with redness and slight rise of temperature, all of which pass off in a few days. It is therefore justifiable to suppose that man occupies an intermediate place in the scale of susceptibility, probably between the dog and the sheep, and that when the pneumococcus gains an entrance to his lungs, the local reaction in the form of pneumonia occurs.

Analogies to the facts just stated are afforded in the case of other diseases caused by bacteria. Thus, for example, the anthrax bacillus produces in the human subject more marked inflammatory reaction, and is more restricted to the local lesions, than in the much more susceptible guinea-pig, in which it produces a rapidly fatal septicæmia and occurs in enormous numbers throughout the blood. An analogous result is also obtained when, instead of taking animals of different susceptibility, the same species of animal is used, but the virulence of the organism is altered; for example, a streptococcus, as already stated, producing at one time an erysipelatous condition, causes an acute septicæmia when its virulence is increased.

The occurrence in the lung of inflammatory conditions due to other causes does not make it less likely that the great majority of cases of acute pneumonia which occur under natural conditions have as the causal irritant the pneumococcus. For in the latter we have an organism with certain very definite microscopic and biological characters, which is certainly present in the great majority of, if not in all, cases of the disease. Its action as a pro-

ducer of general septicæmia in animals, we have seen, finds a perfectly rational explanation in the different degrees of susceptibility which exist towards it in different species. In this connection the occurrence of manifestations of general infection associated with pneumonia in man is of the highest importance. We have seen that meningitis and other inflammations are not very rare complications of the disease, and such cases form a link connecting the local disease in the human subject with the general septicæmic processes which may be produced artificially in the more susceptible representatives of the lower animals.

A fact which has, in the minds of some, rather militated against the pneumococcus being the cause of pneumonia is the discovery of this organism in the saliva of healthy men. This fact was early pointed out by Pasteur, and also by Fraenkel, and the observation has been confirmed by many other observers. It can certainly be isolated from the mouths of a large proportion of normal men, from their nasal cavities, etc., being probably in any particular individual more numerous at some times than at others, and sometimes being entirely absent. This can be proved, of course, by inoculation of susceptible animals. Such a fact, however, does not necessarily imply that the pneumococcus is not the cause of pneumonia. It only implies the importance of predisposing causes in the etiology of the disease, and it is further to be observed that we have corresponding facts in the case of the diseases caused by pyogenic staphylococci, streptococci, the bacillus coli, etc. It is probable that by various causes the vitality and power of resistance of the lung are diminished, and that then the pneumococcus gains an entrance. In relation to this possibility we have the very striking facts that in the irregular forms of pneumonia, secondary to such conditions as typhoid and diphtheria, the pneumococcus is very frequently present, alone or with other organisms. Taking this in conjunction with the fact that the pneumococcus can by itself originate such conditions in susceptible animals, we are justified in the conclusion that the toxines produced by such bacteria

as the B. typhosus and the B. diphtheriæ can devitalise the lung to such an extent that secondary infection by the pneumococcus is more likely to occur and set up pneumonia. We can therefore understand how less definite devitalising agents such as cold, alcoholic excess, etc., can play an important part in the causation of pneumonia. In this way also other abnormal conditions of the respiratory tract, a slight bronchitis, etc., may play a similar part.

It is more difficult to explain why sometimes the pneumococcus is associated with a spreading inflammation, as in croupous pneumonia, whilst at other times it is present in the catarrhal bronchioles and air vesicles in broncho-pneumonia. It is quite likely that in the former condition the organism is possessed of a higher order of virulence, though of this we have no direct proof. We have, however, a closely analogous fact in the case of erysipelas, which, we have stated reasons for believing, is produced by a streptococcus which, when less virulent, causes only local inflammatory and suppurative conditions.

Summary.—We may accordingly summarise the facts regarding the relation of Fraenkel's pneumococcus to the disease by saying that it can be isolated from nearly all cases of acute croupous pneumonia, and also from a considerable proportion of other forms of pneumonia. When injected into the lungs of moderately insusceptible animals it gives rise to pneumonia. If, in default of the crucial experiment of intra-pulmonary injection in the human subject, we take into account the facts we have discussed, we are justified in holding that it is the chief factor in causing croupous pneumonia, and also plays an important part in other forms. Pneumonia, in the widest sense of the term, is, however, not a specific affection, and various inflammatory conditions in the lungs can be set up by the different pyogenic organisms, by the bacilli of diphtheria, of influenza, etc.

The possibility of Friedländer's *pneumobacillus* having an etiological relationship to pneumonia has been much disputed. Its discoverer found that it was pathogenic

towards mice and guinea-pigs, and to a less extent towards dogs. Rabbits appeared to be immune. The type of the disease was of the nature of a septicæmia. No extended experiments, such as those performed by Gamaleia with Fraenkel's coccus, have been done, and therefore we cannot say whether any similar pneumonic effects are produced by it in partly susceptible animals. The organism appears to be present alone in a small number of cases of pneumonia, and the fact that it also appears to have been the only organism present in certain septicæmic complications of pneumonia, such as empyema and meningitis, render it possible that it may be the causal agent in a few cases of the disease.

The Toxines of Fraenkel's Pneumococcus.—Pneumonia is a disease which presents in many respects the characters of an acute poisoning. In very few cases does death take place from the functions of the lungs being interfered with to such an extent as to cause asphyxia. It is from cardiac failure, from grave interference with the heat-regulating mechanism, and from a general nervous depression that death usually results. These considerations, taken in connection with the fact that in man the pneumococci are usually confined to the lung, suggest that they may produce their general effects by means of toxines. The subject has been investigated by Emmerich and Fowitsky and by G. and F. Klemperer. The latter isolated from recent bouillon cultures, by the methods of Brieger and Fraenkel (p. 137) bodies having the reactions of the toxalbumins obtained in the case of other bacteria. When injected, these toxalbumins (which they called "pneumotoxin") produced symptoms in rabbits, and when they were derived not from bouillon cultures but from the blood of animals dead of the disease, they could produce fatal effects. We have seen that the pneumococci rapidly lose their virulence in artificial media, and therefore instead of letting bouillon cultures go on for a month, as in the case of diphtheria, the Klemperers had to be content with two days' growth to obtain the maximum effect. We can say little of the true nature of

these toxines. Their activity is interfered with by an hour's exposure at 60° C., but, as in the case of other toxines, whether they are really proteids, or non-proteid bodies carried down with the latter in the methods of precipitation used, we do not know.

Immunisation against the Pneumococcus.—Animals can be immunised against the pneumococcus either by inoculation with attenuated cultures or by the injection of toxic bodies derived from cultures. The former can be effected by cultures which have become attenuated by growth on artificial media, or by the naturally attenuated cocci which occur in the sputum after the crisis of the disease. Netter effected immunisation by injecting an emulsion of the dried spleen of an animal dead of pneumococcus septicæmia. Here the cocci were attenuated by the drying. Immunisation by toxic products has been effected in various ways. The Klemperers found that injection of rusty sputum kept at 60° C. for one to two hours and then filtered, and of toxine similarly treated, had a like result. In all cases one or two injections of the modified bacteria or toxine were sufficient for immunisation. It was three days in the case of intravenous injection, and fourteen days in the case of subcutaneous injection, before immunity was established, and the latter lasted a month or more. The immunity was accompanied by the development in the blood of antitoxic substances which had no effect either outside or inside the body in killing the pneumococci, but merely neutralised their toxines. Such antitoxines not only protected a rabbit against subsequent inoculation with pneumococci, but if injected within twenty-four hours after inoculation, prevented death.

The interpretation of these immunisation experiments is difficult. Isaeff has denied that antitoxic properties exist in the serum of immunised animals, but in the absence of any attempts to standardise the pneumotoxin, his experiments must be received with caution, as the amount of serum used might be quite insufficient to neutralise the amount of toxine, and yet it might possess antitoxic properties. Others have held in opposition to the Klemperers

that the serum of immunised animals is bactericidal, and the whole subject requires further investigation.

If antitoxines exist, their production may shed new light on what occurs in pneumonia in man. The view has been advanced that the crisis so characteristic of a non-fatal case of the disease occurs when the balance of antitoxine against toxine is in favour of the former. The pneumococci after the crisis, as has been proved both culturally and by inoculation experiments, are still vital and virulent, though not so virulent as when the fever is at its height. On them directly the antitoxine has no effect, but any toxine now elaborated by them is neutralised, and has no longer either local or general pathogenic effects.

A fact interesting as corroborating the view that the pneumococcus is really the cause of acute lobar pneumonia, is that the serum of patients who have recovered from pneumonia has in a certain proportion of cases a protective effect against the pneumococcus in rabbits. So far as our knowledge goes, such a protective serum is specific, or in other words, protects only against the organism by the action of which its protective properties have been produced, and therefore it must be against the pneumococcus that the human subject requires protection in pneumonia.

The Klemperers treated a certain number of cases of human pneumonia by serum derived from immune animals, and with apparently a certain measure of success. These results have been followed up by Washbourn, who immunised ponies against the pneumococcus, and found that their serum had protective powers when tested in other animals. It is still doubtful whether such serum is really antitoxic, and further investigation is necessary.

Methods of Examination.—These have been already described, but may be summarised thus: (1) Microscopic. Stain films from the densest part of the sputum or from the area of spreading inflammation in the lung by Gram's method and by carbol-fuchsin, etc. (p. 188), in the latter case without decolorising the ground-work of the preparation.

(2) By cultures. (*a*) *Fraenkel's pneumococcus.* With

similar material make successive strokes on agar, blood agar or blood serum. The most certain method, however, is to inject some of the material containing the suspected cocci into a rabbit. If the pneumococcus be present the animal will die, usually within forty-eight hours, with numerous capsulated pneumococci in its heart blood. With the latter inoculate tubes of the above media and observe the growth. (*b*) *Friedländer's pneumobacillus* can be readily isolated either by ordinary gelatine plates or by successive strokes on agar media.

CHAPTER IX.

TUBERCULOSIS.

THE cause of tubercle was proved by Koch in 1882 to be the organism now universally known as the tubercle bacillus. Probably no other single discovery has had a more important effect on medical science and pathology than this. It has not only shown what is the real cause of the disease, but has also supplied infallible methods for determining what are tubercular lesions and what are not, and has also given the means of studying the modes and paths of infection. A definite answer has been supplied in this way to many questions which were previously the subject of endless discussion.

Historical.—Klencke in 1843 made the statement that he had produced tuberculosis in rabbits by intravenous injection of tubercular material, but he only concluded from these experiments that the cells of tubercles could multiply and reproduce the disease, and he appears to have placed little importance on the discovery. Villemin has the honour of having been the first to investigate the infectious character of tubercle by systematic experiments, and to demonstrate the regularity with which tuberculosis can be transmitted by inoculation with tubercular material. His first observations were published in 1865. He produced tuberculosis in animals not only by tubercular material from the human subject, but also by portions of what were known as the *perlsucht* nodules in cattle, and came to the

conclusion that *perlsucht* was due to the same virus as tubercle. He concluded that the virus of tubercle was comparable in its mode of action with that of other infectious diseases.

These views, however, aroused a storm of opposition from all sides. The opposition was at first chiefly on theoretical grounds, but later also from experimental results. Investigators who repeated Villemin's experiments obtained similar results so far as the production of tuberculosis by tubercular material was concerned, but many found that tuberculosis also followed inoculation with non-tubercular material (such as pus from pyæmic abscesses, portions of decomposed tissue, etc.), and even by the mere introduction of setons. The general opinion came to be strongly against the existence in tubercle of an infective agent of specific nature, and along with this there prevailed great confusion as to the distinction between tubercular and non-tubercular lesions.

Armanni, in 1873, by scarification of the cornea and inoculation with tubercular material, produced in that situation a small tubercular ulcer, which was afterwards followed by general tuberculosis. Such a result he found never followed inoculation with non-tubercular material. But it was the work of Cohnheim and Salomonsen along similar lines which was chiefly instrumental in altering the general opinion with regard to the non-specific nature of a tubercular virus. By inoculation of the anterior chamber of the eye of rabbits with tubercular material they found that in many cases the results of irritation soon disappeared, but that after a period of incubation, usually about twenty-five days, small tubercular nodules appeared in the iris; and afterwards the disease gradually spread, leading to a tubercular disorganisation of the globe of the eye. Later, the lymphatic glands became involved, and finally the animal died of acute tuberculosis. The question remained as to the nature of the virus the specific character of which was thus established, and this question was answered by the work of Koch.

The announcement of the discovery of the tubercle

bacillus was made by Koch in March 1882, and a full account of his researches appeared in 1884 (*Mitth. a. d. k. Gsndhtsamte*, Berlin). Koch's work on this subject will remain as a classical master-piece of bacteriological research, both on account of the great difficulties which he successfully overcame and the completeness with which he demonstrated the relations of the organism to the disease. The two chief difficulties were, first, the demonstration of the bacilli in the tissues, and, secondly, the cultivation of the organism outside the body. For, with regard to the first, the tubercle bacillus cannot be demonstrated by a simple watery solution of a basic aniline dye, and it was only after prolonged staining for twenty-four hours with a solution of methylene-blue with caustic potash added, that he was able to reveal the presence of the organism. Then, in the second place, all attempts to cultivate it on the ordinary media failed, and he only succeeded in obtaining growth on solidified blood serum, the method of preparing which he himself devised, inoculations being made on this medium from the organs of animals artificially rendered tubercular. The fact that growth did not appear till the tenth day at the earliest, might easily have led to the hasty conclusion that no growth took place. All difficulties were, however, successfully overcome. He cultivated the organism by the above method from a great variety of sources, and by a large series of inoculation experiments on various animals, performed by different methods, he conclusively proved that the bacilli from these different sources produced the same tubercular lesions and were really of the same nature. His work was the means of showing conclusively that such conditions as lupus, "white swelling" of joints, scrofulous disease of glands, etc., are really tubercular in nature.

Tuberculosis in Animals.—Tuberculosis is not only the most widely spread of all diseases affecting the human subject, and produces a mortality greater than any other, but there is probably no other disease which affects the domestic animals so widely. We need not here describe in detail the various tubercular lesions in the human subject,

but some facts regarding the disease in the lower animals may be given, as this subject is of great importance in relation to the infection of the human subject.

Amongst the domestic animals the disease is commonest in cattle (bovine tuberculosis), and in them the lesions are very various, both in their character and distribution. In most cases the lungs are affected, and contain numerous rounded nodules, many being of considerable size; these may be softened in the centre, but are usually of pretty firm consistence and may be calcified. There may be in addition caseous pneumonia, and also small tubercular granulations. Along with these changes in the lungs, the pleuræ are also often affected, and show numerous nodules, some of which may be of large size, firm and pedunculated, the condition being known in Germany as *Perlsucht*, in France as *pommelière*. Lesions similar to the last may be chiefly confined to the peritoneum and pleuræ. In other cases, again, the abdominal organs are principally involved. The udder becomes affected in a certain proportion of cases of tuberculosis in cows—in 3 per cent according to Bang—but primary affection of this gland is very rare. Tuberculosis is also a comparatively common disease in pigs, in which animals it in many cases affects the abdominal organs, in other cases produces a sort of caseous pneumonia, and sometimes is met with as a chronic disease of the lymphatic glands, the so-called "scrofula" in pigs. In pigs tubercular lesions in the muscles are less rare than in most other animals. In the horse the abdominal organs are usually the primary seat of the disease, the peritoneum, lymphatic glands, liver, and spleen being extensively affected; the last-mentioned organ may be enormously enlarged and crowded with nodules of various shapes and sizes. In sheep and goats tuberculosis is comparatively rare, though cases are occasionally met with. It also occurs spontaneously in dogs, cats, and in the large carnivora. It is also sometimes met with in monkeys in confinement, and leads to a very rapid and widespread affection in these animals, the nodules

having a special tendency to soften and break down into a pus-like fluid.

Tuberculosis in fowls (avian tuberculosis) is a common and very infectious disease, nearly all the birds in the poultry-yard being sometimes affected. It is considered by some that the bacillus in avian tuberculosis is different from that in the mammalian form. This question will be discussed below. Further statements with regard to tuberculosis artificially produced will be given later.

From these statements it will be seen that the disease in animals presents great variations in character, and may differ in many respects from that met with in the human subject. The tubercle nodules may be of so large a size, *e.g.*, in the horse and ox, as to be described as sarcoma-like; they may be tough and firm, with little or no caseation, or they may be softened in the centre, more resembling abscesses, or again there may be an eruption of very minute granulations. However different their naked-eye appearances may be, they are built up histologically on the same plan, and of greater importance still is the fact that they are all produced by the tubercle bacillus.

FIG. 56.—Tubercle bacilli, from a pure culture on glycerine agar. Stained with carbol-fuchsin. × 1000.

Tubercle Bacillus —Microscopical Characters. — Tubercle bacilli are minute rods which usually measure 2.5 to 3.5 μ in length, and .3 μ in thickness, *i.e.* in proportion to their length they are comparatively thin organisms (Figs. 56 and 57). Sometimes, however, longer forms, up to 5 μ or more in length, are met with, both in cultures and

in the tissues. They are straight or slightly curved, and appear of uniform thickness, and, when stained, are uniformly coloured, or may present small uncoloured spots along their course, with darkly-stained parts between. In the case of the tubercle bacillus, as of many other organisms, a considerable amount of discussion has taken place as to the occurrence of spores. In such a minute organism it is extremely difficult to recognise the exact characters of the unstained points. Accordingly, we find that some consider these to be of the nature of spores, while others find that it is impossible to stain them by any means whatever, and consider that they are really of the nature of vacuoles. Others again hold that some of the condensed and highly-staining particles are of the nature of spores. It is impossible to speak dogmatically on the question at present. We can only say that the younger bacilli stain uniformly, and that in the older forms this inequality in staining is met with, but it has not been definitely proved that this always indicates spore formation. Bacilli with their protoplasm thus broken up often appear like short rows of cocci.

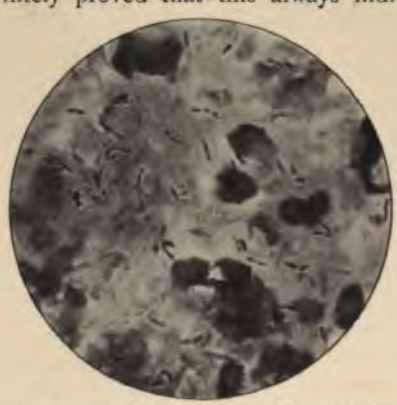

FIG. 57.—Tubercle bacilli in phthisical sputum.
Film preparation, stained with carbol-fuchsin and methylene-blue. × 1000.

The bacilli in the tissues occur scattered irregularly or in little masses. They are usually single, or two are attached end to end, and often form in such a case an obtuse angle. True chains are not formed, but occasionally short filaments are met with. In cultures the bacilli form masses in which the rods are closely applied to one another and

arranged in a more or less parallel manner. Tubercle bacilli are quite devoid of motility.

Aberrant Forms.—Though such are the characters of the organism as usually met with, other appearances are sometimes found. In old cultures, for example, very much larger elements may occur. These may be in the form of long filaments, which may be swollen or clubbed at their extremities, may be irregularly beaded, and may even show the appearance of branching. Such forms have been studied by Metchnikoff, Maffucci, Klein, and others. Their significance has been variously interpreted, for while some look upon them as degenerated or involution forms, others regard them as indicating a special phase in the life history of the organism. This latter view, however, has many facts against it, especially the circumstance that these aberrant forms are chiefly met with when the organisms are undergoing retrogressive change. The question, however, is one which at present is not definitely settled.

Staining Reactions.—The tubercle bacillus takes up the ordinary stains with great slowness, and for successful staining one of the most powerful solutions ought to be em ployed, *e.g.*, gentian-violet or fuchsin, along with aniline oil water, or solution of carbolic acid. Further, such staining solutions require to be applied for a long time, or the staining must be accelerated by heat, the solution being warmed till steam arises and the specimen allowed to remain in the hot stain for two or three minutes. It was at first supposed that the organism could not be coloured at all by a simple watery solution of a basic aniline stain. This is not strictly correct, but the colour is taken up with great slowness and very faintly. As stated above, Koch at first used a solution of methylene-blue with caustic potash added, but even this method stains somewhat faintly, and he afterwards abandoned it in favour of the combination of aniline oil with gentian violet, introduced by Ehrlich. One of the best and most convenient methods is the Ziehl-Neelsen method (see p. 102). The bacilli present this further peculiarity, however, that after staining has taken place they

resist decolorising by solutions which readily remove the colour from the tissues and from other organisms which may be present. Such decolorising agents are sulphuric or nitric acid in 20 per cent solution. Preparations can thus be obtained in which the tubercle bacilli alone are coloured by the stain first used, and the tissues can then be coloured by a contrast stain. Leprosy bacilli, however, retain the stain in the same way, though not so firmly, as tubercle bacilli, and thus constitute an exception to this reaction being peculiar to the latter. Even the spores of many bacilli become decolorised more readily than tubercle bacilli, though some retain the colour with equal tenacity.

FIG. 58.—Cultures of tubercle bacilli on glycerine agar.

A and B. Mammalian tubercle bacilli; A is an old culture, B one of a few weeks' growth.
C. Avian tubercle bacilli. The growth is whiter and smoother on the surface than the others.

Cultivation. — The medium first used by Koch was inspissated blood serum (*vide* p. 47). If inoculations are made on this medium with tubercular material free from other organisms there appear from the tenth to fourteenth day minute points of growth of dull whitish colour, rather irregular, and slightly raised above the surface. In such cultures they usually reach only a comparatively small size and remain separate, becoming confluent only when many

occur close together. Koch compared the appearance of these to that of small dry scales. In sub-cultures, however, growth is more luxuriant and may come to form a dull wrinkled film of whitish colour, which may cover the greater part of the surface of the serum and at the bottom of the tube may grow over the surface of the condensation water on to the glass (Fig. 58, A). The growth is always of a dull appearance and has a considerable degree of consistence, it being difficult to dissociate a portion thoroughly in a drop of water. In older cultures the growth may acquire a slightly brownish or buff colour. When the small colonies are examined under a low power of the microscope they are seen to be extending at the periphery in the form of wavy or sinuous streaks which radiate outward and which have been compared to the flourishes of a pen. The central part shows similar markings closely interwoven. These streaks are composed of masses of the bacilli arranged in a more or less parallel manner.

On *glycerine agar*, which was first introduced by Nocard and Roux as a medium for the culture of the tubercle bacillus, growth takes place in sub-cultures at an earlier date and progresses more rapidly than on serum, but, strangely enough, this medium is not suitable for obtaining cultures from the tissues, inoculations with tubercular material usually yielding a negative result. The growth has practically the same characters as on serum, but is more luxuriant. It, however, tends to lose its virulence more rapidly than when grown on serum. In *glycerine broth*, especially when the layer is not deep, tubercle bacilli grow readily in the form of little white masses which fall to the bottom and form a powdery layer. If, however, the growth be started on the surface it spreads superficially as a dull whitish, wrinkled pellicle which may reach the walls of the flask. The culture has a peculiar fruity and not unpleasant odour. On ordinary agar and on gelatine media no growth takes place.

It was at one time believed that the tubercle bacillus would only grow on media containing animal fluids, but of

late years it has been found that growth takes place also on a purely vegetable medium, as was first shown by Pawlowsky in the case of potatoes. Sander has shown that the bacillus grows readily on potato, carrot, macaroni, and on infusion of these substances, especially when glycerine is added. He also found that cultures could be more easily made on potato from tubercular lesions than on glycerine agar. In the case of the decoctions used by Sander, as in glycerine broth, the growth forms a wrinkled membrane on the surface.

The optimum temperature for growth is 37° to 38° C. Growth ceases above 42° and usually below 28°, but on long-continued cultivation outside the body and in special circumstances, growth may take place at a lower temperature, *e.g.* Sander found that growth took place in potato broth even at 22° to 23° C.

Powers of Resistance.—Tubercle bacilli have considerable powers of resistance to external influences, and can retain their vitality for a long time outside the body in various conditions. In this respect they resemble bacilli which are known to possess spores, and this is really the chief argument in favour of the presence of spores in the tubercle bacilli, though their resisting power is considerably less than that of most spore-containing bacilli. Dried phthisical sputum has been found to contain still virulent bacilli or their spores after two months, and similar results are obtained when the bacilli are kept in distilled water for several weeks. So also they resist for a long time the action of putrefaction, which is rapidly fatal to many pathogenic organisms. Sputum has been found to contain living tubercle bacilli even after being allowed to putrefy for several weeks (Fraenkel, Baumgarten), and the bacilli have been found to be alive in tubercular organs which have been buried in the ground for a similar period. They are not killed by being exposed to the action of the gastric juice for six hours, or to a temperatue of – 3° C. for three hours, even when this is repeated several times. It has been found that when completely dried they can resist a tempera-

ture of 100° C. for an hour, but, on the other hand, exposure in the moist condition to 70° C. for the same time is usually fatal. It may be stated that raising the temperature to 100° C. kills the bacilli in fluids and in tissues, but in the case of large masses of tissue care must be taken that this temperature is reached throughout. They are killed in less than a minute by exposure to 5 per cent carbolic acid, and both Koch and Straus found that they are rapidly killed by being exposed to the action of direct sunlight.

Action on the Tissues.—The lesion produced by the tubercle bacillus is the well-known tubercle nodule, but though the typical structure is often described as consisting of a central giant cell surrounded by a zone of comparatively large and somewhat spindle-shaped cells (epithelioid cells), and again by an outer zone of lymphocytes or small uninucleated leucocytes, the structure varies in different situations and according to the intensity of the action of the bacilli.

A considerable discussion has taken place as to the exact origin of the elements composing the tubercle follicle. In the case of the iris its formation was fully studied by Baumgarten, and his views we consider to be correct regarding the ordinary mode of formation. Before describing the exact changes which occur in the tissues, it may be stated that the action of the bacillus is twofold. On the one hand, by its irritation it induces tissue-reaction in the form of proliferative changes and leucocytic infiltration, and on the other hand, it causes degenerative changes in the cells around, which afterwards result in their death.

After the bacilli gain entrance to a connective tissue such as that of the iris, their first action appears to be on the connective tissue cells, which become somewhat swollen and undergo mitotic division, the resulting cells being distinguishable by their large size and pale nuclei. These constitute the so-called epithelioid cells. These proliferative changes may be well seen on the fifth day after inoculation or even earlier. A small focus of proliferated cells is thus formed in the neighbourhood of the bacilli and about the same time numbers of leucocytes of the small uninucleated

variety begin to appear at the periphery and gradually become more numerous.

Soon, however, the action of the bacilli as cell-poisons comes into prominence, the changes first occurring in the centre of the focus. The epithelioid cells become swollen and somewhat hyaline, their outlines become indistinct, whilst their nucleus stains faintly, and ultimately loses the power of staining. The cells in the centre, thus altered, gradually become fused into a homogeneous substance and this afterwards becomes somewhat granular in appearance. If leucocytes are involved in this necrotic change their nuclei generally break down into small granular particles, which stain deeply and may remain visible for a considerable time. If the central necrosis does not take place very quickly, then giant-cell formation may occur in the centre, this constituting one of the characteristic features of the tubercular lesion. The giant cells in tubercle are large, rounded, or oval protoplasmic masses, often with numerous processes, and containing a varying number of oval nuclei somewhat poor in chromatin, which are often arranged in a ring towards the periphery, sometimes collected in a clump towards one end, and sometimes lying irregularly. The centre of a giant cell often shows signs of degeneration, such as hyaline change and vacuolation, or it may be more granular than the rest of the cell.

Though there has been a considerable amount of discussion as to the mode of origin of the giant cells, we think there can be little doubt that in most cases they result from enlargement of single epithelioid cells, the nucleus of which undergoes proliferation without the protoplasm dividing. Sometimes cells a little larger than epithelioid cells may be seen, which contain only two or three nuclei; these may be young giant cells. Some consider that the giant cells result from a fusion of the epithelioid cells; but though there are occasionally appearances which suggest such a mode of formation, it cannot be regarded as of common occurrence. In some cases of acute tuberculosis, when the bacilli become lodged in a capillary the endothelial cells

of its wall may proliferate, and thus a ring of nuclei be formed round a small central thrombus. Such an occurrence gives rise to an appearance closely resembling a typical giant cell.

Giant cells are found especially when the caseous change is relatively not very active—that is, in circumstances where the formative processes have time to come into play. If the centre of the nodule becomes caseous, giant cells may be formed later in the cellular tissue at the periphery. According to the view here stated, both the epithelioid and the giant cells are of connective tissue origin; and we can see no sufficient evidence for the view held by some observers, chiefly of the French school, that they are formed from leucocytes which have emigrated from the capillaries.

Such are the usual changes which occur on the introduction of the bacilli into connective tissue; but the tubercle nodule has not always the same mode of formation and structure. In very acute tuberculosis of the spleen, for example, a group of bacilli may often be seen to have caused cellular necrosis around them before any tissue proliferation has taken place, and it may be only at the margin of the larger and older follicles that epithelioid cells are well seen. In very acute tuberculosis, also, the commencement of the tubercle nodule may sometimes be traced to a clump of leucocytes surrounding bacilli in a capillary; such an appearance may sometimes be met with in the liver. The great varieties in the appearance of tubercular lesions depend upon the number of the bacilli and their manner of spread, and accordingly on the proportion in which the proliferative and degenerative changes occur. We thus find that the cellular proliferation is especially marked when the bacilli are few in number.

There can be no doubt, we think, from a careful study of the tubercular lesions, that the cell necrosis and ultimate caseation depend upon the products of the bacilli, and are not due to the fact that the tubercle nodule is non-vascular. This non-vascularity itself is to be explained by

the circumstance that young capillaries cannot grow into a part where tubercle bacilli are active, and that the already existing capillaries become thrombosed, owing to the action of the bacillary products on their walls, and ultimately disappear. At the periphery of tubercular lesions there may be considerable vascularity and new formation of capillaries.

Presence and Distribution of the Bacilli.—A few facts may be stated regarding the presence of bacilli, and the numbers in which they are likely to be found in tubercular lesions. On the one hand, they may be very few in number and difficult to find, and on the other hand, they may be present in very large numbers, sometimes forming masses which are easily visible under the low power of the microscope.

They are usually very few in number in chronic lesions, whether the latter are tubercle nodules with much connective tissue formation or old caseous collections. In caseous material one can sometimes see a few bacilli faintly stained, along with very minute unequally stained granular points, some of which may be spores of the bacilli. Whether they are spores or not, the important fact has been established that tubercular material in which no bacilli can be found microscopically, may be proved, on experimental inoculation into animals, to be still virulent. In such cases the bacilli may be present in numbers so small as to escape observation, or their spores only may be present. In subacute lesions, with well-formed tubercle follicles and little caseation, the bacilli are generally scanty. They are most numerous in acute tubercular lesions, especially where caseation is rapidly spreading, for example, in such conditions as caseous catarrhal pneumonia (Fig. 59), acute tuberculosis of the spleen in children, which is often attended with a good deal of rapid caseous change, etc. In acute miliary tuberculosis a few bacilli can generally be found in the centre of the follicles; but here they are often much more scanty than one would expect. The tubercle bacillus is one which not only has comparatively slow growth, but

retains its form and staining power for a much longer period than most organisms. This is true of the bacilli both in cultures and also in the tissues.

As regards their position in the tissues, the bacilli are usually scattered irregularly or in small groups amongst the cells or granular material. Most of the bacilli lie free

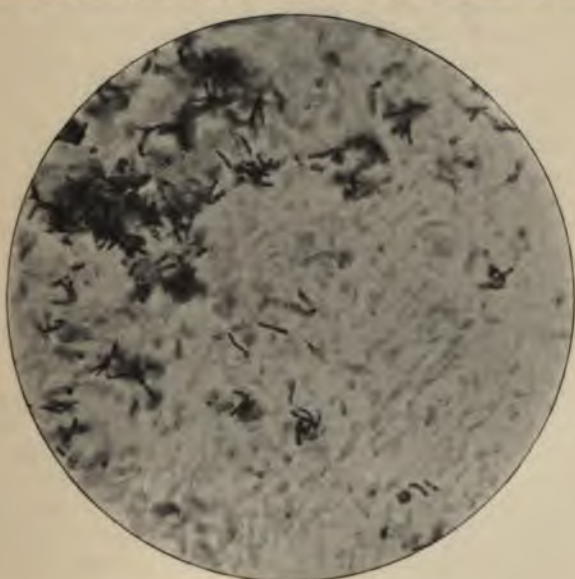

FIG. 59.—Tubercle bacilli in section of human lung in acute phthisis. The bacilli are seen lying singly, and also in large masses to left of field. The pale background is formed by caseous material.
Stained with carbol-fuchsin and Bismarck-brown. × 1000.

between the cells in the connective tissues, and their occurrence within the cells is proportionately not common, there being in this respect a contrast to what is seen in the lesions in leprosy. Occasionally we find them within the giant cells, in which they may be arranged in a somewhat radiate manner at the periphery, occasionally also in epithel-

ioid cells and in leucocytes; but these are by no means frequent sites.

The above statements, however, apply only to tuberculosis in the human subject, and even in this case there are exceptions. In the ox, on the other hand, the presence of tubercle bacilli within giant cells is a very common

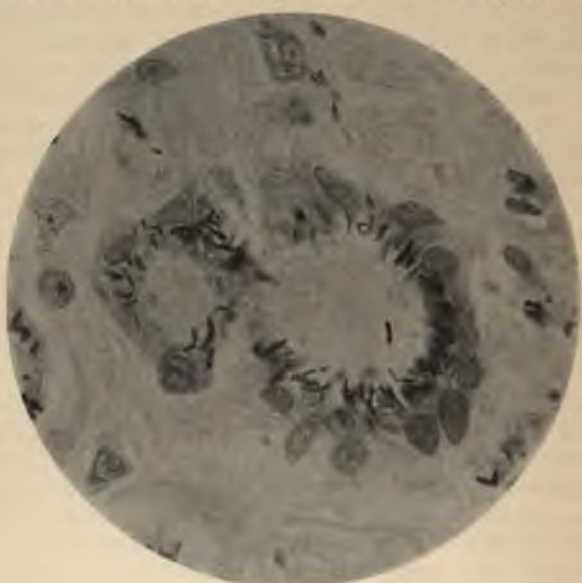

FIG. 60.—Tubercle bacilli in giant-cells, showing the radiate arrangement at the periphery of the cells. Section of tubercular udder of cow. Stained with carbol-fuchsin and Bismarck-brown. × 1000.

occurrence; and it is also common to find them in considerable numbers scattered irregularly throughout the cellular connective tissue of the lesions, even when there is little or no caseation present (Fig. 60).

In tuberculosis in the horse and in avian tuberculosis the numbers of bacilli may be enormous, even in lesions which are not specially acute; and considerable variation

both in their number and in their site is met with in tuberculosis of other animals. Cellular necrosis and caseation occur in proportion to the numbers of the bacilli present, much more readily in some animals than in others, probably owing to different degrees of susceptibility of their tissues.

In discharges from tubercular lesions which are breaking down, tubercle bacilli are usually to be found. In the sputum of phthisical patients their presence can be demonstrated almost invariably at some period, and sometimes their numbers are very large (for method of staining see p. 102). In cases of genito-urinary tuberculosis they are often present in the urine; but as they are much diluted it is difficult to find them unless a very complete formation of deposit is allowed to take place. This deposit is examined in the same way as the sputum. It is, however, much easier to obtain their separation by means of the centrifuge; and if this method is employed, they can usually be found, though sometimes their number may be very small. The bacilli often occur in little clumps, as shown in Fig. 61. In tubercular ulceration of the intestine their presence in the fæces may be demonstrated, as was first shown by Koch; but in this case their discovery is usually of little importance, as the intestinal lesions, as a rule, occur only in advanced stages when diagnosis is no longer a matter of doubt.

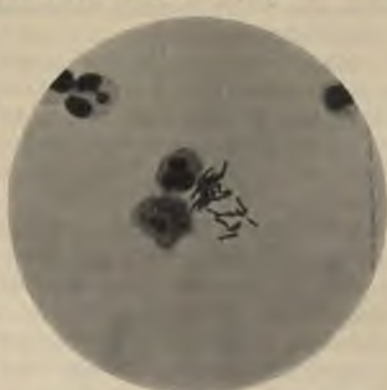

FIG. 61.—Tubercle bacilli in urine; showing one of the characteristic clumps, in which they often occur.

Stained with carbol-fuchsin and methylene blue. × 1000.

Experimental Inoculation.—Tuberculosis can be arti-

ficially produced in animals by infection in a great many different ways—by injection of the bacilli into the subcutaneous tissue, into the peritoneum, into the anterior chamber of the eye, into the veins ; by feeding the animals with the bacilli ; and, lastly, by making them inhale the bacilli suspended in the air.

The exact result, of course, varies in different animals and according to the method of inoculation, but we may state generally that when introduced locally into the tissues of a susceptible animal, the bacilli usually produce the lesions above described, terminating finally in a local caseation ; that there then occurs a tubercular affection of the neighbouring lymphatic glands, and that lastly there may be a rapid extension of the bacilli to other organs by the blood stream, and the production of general tuberculosis. Of the animals used for the purpose, the guinea-pig is most susceptible, the rabbit less so, while the dog has considerable powers of resistance.

When a guinea-pig is inoculated subcutaneously with tubercle bacilli from a culture, or with material containing them, such as phthisical sputum, a local swelling gradually forms which is usually well marked about the tenth day. This swelling becomes softened and caseous, and breaks down, leading to the formation of an irregularly ulcerated area with caseous lining. The lymphatic glands in relation to the parts can generally be found to be enlarged, and of somewhat firm consistence, about the end of the second or third week. Later, in them also caseous change occurs, and a similar condition may spread to other groups of glands in turn, passing also to those on the other side of the body. During the occurrence of these changes, the animal loses weight, shows general disturbance of nutrition, gradually becomes cachectic, and dies, death occurring sometimes within six weeks, sometimes not for two or three months. *Post mortem*, in addition to the local and glandular changes, an acute tuberculosis is usually present, the spleen being specially affected. This organ is swollen, and is studded throughout by numerous tubercle nodules, which may be

minute and grey, or larger and of a yellowish tint. If death has been long delayed, calcification may have occurred in some of the nodules. Tubercle nodules, though rather less numerous, are also present in the liver and in the lungs, the nodules in the latter organs being usually of smaller size, though sometimes extremely numerous. The extent of the general tuberculosis varies in different cases, sometimes chronic glandular changes being the outstanding feature.

Intraperitoneal injection of pure cultures produces a local lesion in the form of an extensive tubercular infiltration and thickening of the omentum, sometimes attended with acute tubercles all over the peritoneum. There is a caseous enlargement of the retro-peritoneal and other lymphatic glands, and later there may be a general tuberculosis. *Intravenous* injection produces a typical acute tuberculosis, the nodules being usually more numerous and of smaller size, while death follows more rapidly, generally within three weeks, the larger the numbers of bacilli injected. Guinea-pigs, when fed with tubercle bacilli, or with sputum or portions of tissue containing them, readily contract an intestinal form of tuberculosis, lesions being present in the lymphoid tissue of the intestines, in the mesenteric glands, and later in the internal organs.

Rabbits are less susceptible than guinea-pigs, and in them the effects of subcutaneous inoculation are somewhat variable, as sometimes the lesions remain local, sometimes a general tuberculosis is set up. Otherwise the reactions are much of the same nature. Dogs are much more highly resistent, but tuberculosis can be produced in them by intraperitoneal injections of pure cultures (Koch), or by intravenous injection (Maffucci). In the latter case there results an extensive eruption of minute miliary tubercles.

Tuberculosis can also be easily produced in susceptible animals by making them inhale the bacilli. Koch, for this purpose, used pure cultures which were mixed with distilled water, and then distributed in the air by means of a spray. Rabbits, guinea-pigs, and mice were exposed by

this means to inhalations for half an hour on three successive days, and were afterwards kept in healthy conditions. Some of the rabbits and guinea-pigs died within four weeks, the others were killed at the end of that time, and all showed tubercular lesions in the lungs which, in the case of the rabbits and the guinea-pigs, were in the form of patches of caseating catarrhal pneumonia.

To obtain pure cultures of the tubercle bacilli, the acute lesions in the organs of an animal recently killed should be selected, *e.g.*, the spleen of a guinea-pig with early acute tuberculosis. If the lesions are subacute or chronic with much caseation, attempts at cultivation often fail. It would appear as if a considerable number of bacilli required to be present to start the growth. The portions of tissue must, of course, be taken with aseptic precautions, the knives, scissors, etc., to be used being carefully sterilised, and the inoculations should be made on solidified blood serum.

Avian Tuberculosis.—There can be no doubt that the bacilli present in tuberculosis of the various mammals mentioned are of the same variety, though differences in virulence may be occasionally noticed. There has, however, of late years been considerable discussion as regards the identity of the bacilli in avian and mammalian tuberculosis. In the tubercular lesions in birds there are found bacilli which correspond in their staining reactions and in their morphological characters with those in mammals, but differences are observed in cultures, and also on experimental inoculation. Koch, at the International Medical Congress in 1890, related how he had received from other observers some cultures of tubercle bacilli which showed differences in culture, and which led, on experimental inoculation, to conflicting results. He made various attempts, by altering the conditions of growth, etc., to modify these cultures so as to make them conform to ordinary tubercle bacilli, but failed. Later, by accident, he found, on cultivating the bacilli from tuberculosis of fowls, that the cultures obtained corresponded with those which showed the peculiarities referred to. He thus found that important

points of distinction existed between the tubercle bacilli from mammals and those from birds, though he did not conclude therefrom that they were quite distinct species. Maffucci and Rivolta had already drawn attention to, and studied, these differences.

On glycerine-agar and on serum, the growth of tubercle bacilli from birds is more luxuriant, has a moister appearance (Fig. 58, C), and, moreover, takes place at a higher temperature, 43·5° C., than is the case with ordinary tubercle bacilli. Experimental inoculation brings out even more distinct differences. Tubercle bacilli derived from the human subject, for example, when injected into birds, usually fail to produce tuberculosis, whilst those of avian origin very readily do so. Birds are also very susceptible to the disease when fed with portions of the organs of birds containing tubercle bacilli, but they can consume enormous quantities of phthisical sputum without becoming tubercular (Straus, Wurtz, Nocard). No doubt, on the other hand, there are cases on record in which the source of infection of a poultry yard has apparently been the sputum of phthisical patients. Again, tubercle bacilli cultivated from birds have not the same effect, on inoculation of mammals, as ordinary tubercle bacilli. When guinea-pigs are inoculated subcutaneously sometimes death follows; generally, however, it does not. In the former case, usually no tubercles visible to the naked eye are found, but numerous bacilli may be present in internal organs, especially in the spleen, which is much swollen. Intravenous injection in guinea-pigs and rabbits produces a fatal result, in the case of the latter in two or three weeks, but here again there is no eruption of ordinary tubercles, though there may be marked enlargement of the spleen and the number of bacilli in it and other organs may be very great. Further, intravenous injection even of large quantities of avian tubercle bacilli, in the case of dogs, leads to no effect, whereas ordinary tubercle bacilli produce acute tuberculosis.

There is, therefore, abundant evidence that the bacilli derived from the two classes of animals show important

differences, and, reasoning from analogy, we might infer that probably the human subject also would be little susceptible to infection from avian tuberculosis. The question, however, still remains as to whether avian tubercle bacilli can assume the characters and properties of those from mammals, or, in other words, whether they are merely varieties of the same species. Without giving in detail the results of observations on this subject, we may state that there is now sufficient evidence that the one variety can assume the properties of the other. It has been found that occasionally the inoculation of fowls with tubercle bacilli from the human subject produces tuberculosis, and that, when this occurs, the disease can be readily transmitted to other fowls. Also in some cases, inoculation with avian tubercle bacilli produces ordinary tubercle nodules in guinea-pigs and rabbits (Courmont and Dor), and, in other cases, these lesions are found after the bacilli have been passed through the tissues of a number of guinea-pigs. It therefore appears that the bacilli of avian tuberculosis are not a distinct and permanent species, but a variety which has been modified by growth in the tissues of the bird. And probably, to judge from the somewhat conflicting results of experiments, there are degrees of this modification, according to the period of time during which the bacilli have passed from bird to bird. It may also be added that tuberculin prepared from avian tubercle bacilli has the same action as the ordinary tuberculin.

Action of dead Tubercle Bacilli.—The remarkable fact has been established by independent investigators that tubercle bacilli in the dead condition, when introduced into the tissues in sufficient numbers, can produce tubercle-like nodules. Prudden and Hodenpyl, by intravenous injection in rabbits of cultures sterilised by heat, produced in the lungs small nodules in which giant cells were occasionally present, but no caseation, and which were characterised by more growth of fibrous tissue than in ordinary tubercle. The subject has been very fully investigated with confirmatory results by Straus and Gamaleia, who find that, if

the number of bacilli introduced into the circulation is large, there result very numerous tubercle nodules with well-formed giant cells, and occasionally traces of caseation. The bacilli can be well recognised in the nodules by the ordinary staining method. In these experiments the bacilli were killed by exposure to a temperature of 115° C. for ten minutes before being injected. Similar nodules can be produced by intraperitoneal injection. Subcutaneous injection, on the other hand, produces a local abscess, but in this case no secondary tubercles are found in the internal organs. Further, in many of the animals inoculated by the various methods a condition of marasmus sets in and gradually leads to a fatal result, there being great emaciation before death. These experiments, which have been confirmed by other observers, show that even after the bacilli are dead they preserve their staining reactions in the tissues for a long time, and also that there are apparently contained in the bodies of the dead bacilli certain substances which act locally, producing proliferative and, to a less extent, degenerative changes, and which also markedly affect the general nutrition. The long period during which the tubercle bacillus, as compared with other organisms, retains even when dead its morphological and staining characters, is a very striking feature.

Practical Conclusions.—From the facts above stated with regard to the conditions of growth of the tubercle bacilli, their powers of resistance, and the paths by which they can enter the body and produce disease (as shown by experiment), the manner by which tuberculosis is naturally transmitted can be readily understood. Though the experiments of Sander show that tubercle bacilli can multiply on vegetable media to a certain extent at warm summer temperature, it is doubtful whether all the conditions necessary for growth are provided to any extent in nature. At any rate, the great multiplying ground of tubercle bacilli is the animal body, and tubercular tissues and secretions containing the bacilli are the chief, if not the only, means by which the disease is spread. The tubercle bacilli leave

the body in large numbers in the sputum of phthisical patients, and when the sputum becomes dried and pulverised they become set free in the air. Their powers of resistance in this condition have already been stated. As examples of the extent to which this takes place, it may be stated that their presence in the air of rooms containing phthisical patients has been repeatedly demonstrated. Williams placed glass plates covered with glycerine in the ventilating shaft of the Brompton Hospital, and after five days found, by microscopic examination, tubercle bacilli on the surface, whilst Klein found that guinea-pigs kept in the ventilating shaft became tubercular. Cornet produced tuberculosis in rabbits by inoculating them with dust collected from the walls of a consumptive ward. Tubercle bacilli are also discharged in considerable quantities in the urine in tubercular disease of the urinary tract, and also by the bowel when there is tubercular ulceration, but, so far as the human subject is concerned, the great means of disseminating the bacilli in the outer world is dried phthisical sputum, and the source of danger from this means can scarcely be over-estimated. Every phthisical patient ought to be looked upon as a fruitful source of infection to those around, and the sputum ought in every case to be collected in special receptacles and thoroughly sterilised either by boiling or by the addition of a 5 per cent solution of carbolic acid.

Another great source of infection is almost certainly the milk of cows affected with tuberculosis of the udder. In such cases the presence of tubercle bacilli in the milk can usually be readily detected by centrifugalising it, and then examining the deposit microscopically, or by inoculating an animal with it. As pointed out by Woodhead and others, the milk from cows thus affected is probably the great source of tabes mesenterica, which is so common in young subjects. In these cases there may be tubercular ulceration of the intestine, or it may be absent. Woodhead found that out of 127 cases of tuberculosis in children, the mesenteric glands showed tubercular affection in 100, and

that there was ulceration of the intestine in 43. It is especially in children that this mode of infection occurs, as in the adult ulceration of the intestine is rare as a primary affection, though it is common in phthisical patients as the result of infection by the bacilli in the sputum which has been swallowed. There is less risk of infection by means of the flesh of tubercular animals, for, as stated by the recent Tuberculosis Commission, in the first place, tuberculosis of the muscles of oxen being very rare, there is little chance of the bacilli being present in the flesh unless the surface has been smeared with the juice of the tubercular organs, as in the process of cutting up the parts; and in the second place, even when present they will be destroyed if the meat is thoroughly cooked.

We may state, therefore, that the two great modes of infection are by inhalation and by ingestion, of tubercle bacilli. By the former method the tubercle bacilli will in most cases be derived from the human subject; in the latter, probably from tubercular cows, though contamination of food by tubercular material from the human subject may also occur. It is quite possible that bacilli from these two sources may be of somewhat different virulence towards the human subject, but at present we have not the means of speaking definitely on this point. Both in inhalation and in ingestion, tubercle bacilli may lodge about the pharynx and thus come to infect the pharyngeal lymphoid tissue, tonsils, etc., tubercular lesions of these parts being much more frequent than was formerly supposed. Thence the cervical lymphatic glands may become infected, and afterwards other groups of glands, bones, or joints, and internal organs.

Koch's Tuberculin.—We have seen that the pathology of tuberculosis indicates that the tubercle bacillus can act on tissues with which it is not immediately in contact, and therefore it is natural to ask whether it, like other organisms, produces definite toxic bodies. What knowledge we have of the latter is secondary to the bringing forward by Koch of a substance he called "tuberculin," which he intro-

duced as a curative agent for tubercular affections. He had observed that if in a guinea-pig suffering from the initial local induration occurring after subcutaneous inoculation with tubercle bacilli, a second subcutaneous inoculation of tubercle bacilli, or of dead cultures of the same, was practised in another part of the body, superficial ulceration occurred in the primary tubercular nodule, the wound healed, and the animal did not succumb to tuberculosis. There thus appeared to exist in tubercle cultures a substance having a healing action in tuberculosis, and an extract containing this substance Koch named tuberculin. A veal bouillon containing 1 per cent peptone, and 4 to 5 per cent glycerine, was inoculated with tubercle bacilli and incubated for from six to eight weeks at 38° C. It was evaporated to $\frac{1}{10}$th of its bulk, and the bacilli were killed by an hour's exposure at 100° C. The result was the tuberculin, and it would evidently contain dead, and often macerated, bacilli,—and whatever substances these bacilli contained,—non-volatile products formed by them from the food material when alive, and the concentrated remains of the bouillon and glycerine. The bacterial products present, whether originally extra- or intra-cellular, would only be such as would not be destroyed at 100° C. The injection of .25 c.c. of tuberculin into a healthy man causes, in three to four hours, malaise, tendency to cough, laboured breathing, and moderate pyrexia; all of which pass off in twenty-four hours. The injection (the site of the injection being quite unimportant), however, of .01 c.c. into a tubercular person gives rise to similar symptoms, but in a much more aggravated form, and in addition there occurs around any tubercular focus great inflammatory reaction, resulting in necrosis and a casting off of the tubercular mass, when this is possible. These appearances could be well seen in such a superficial tuberculosis as lupus. The bacilli were, it was shown, not killed in the process. Koch's theory of the action of the substance was that the tubercle bacillus ordinarily secretes a body having a necrotic action on the tissues. This body is contained in tuberculin, and when the

latter is injected into a tubercular patient, the proportion of necrosis-producing substance round a tubercular focus being suddenly increased, necrosis of the spreading margin occurs very rapidly, inflammatory reaction takes place around, and the material containing the living or dead bacilli is thrown off *en masse* instead of being disintegrated piecemeal.

The publication of these results in the end of 1890 and the beginning of 1891 raised great hopes that a means of combating tuberculosis had been at last discovered, and the earlier results of the treatment of lupus especially appeared to be attended with success. Such hopes were, however, soon seen not to be justified. Koch had stated that the cases of tuberculosis likely to be most benefited were those of early phthisis without cavities and of lupus. Undoubtedly, in the early days of the treatment many cases were treated which did not belong to those classes, but, even in apparently suitable cases, it was very difficult to see how the necrosed material containing the still living bacilli could be got rid of either naturally, as would be necessary in the case of a small tubercular deposit in a lung or a lymphatic gland, or artificially, as in a complicated joint-cavity where surgical interference could, as Koch had himself recommended, be undertaken. Not only so, but the ulceration which might be the sequel of the necrosis appeared to open a path for fresh infection. Again, it is well known that isolated bacilli may occur in the normal tissue at some distance from a tubercular nodule. Now, while these would probably not be cast off in the necrosed tissue the cells around them might be so depressed by the tuberculin as to make them an easier prey to the bacilli. Soon facts were reported which bore out these theoretical considerations. Virchow threw the weight of his authority against the treatment by adducing cases where rapid acute tubercular conditions ensued on the use of tuberculin. His views were confirmed by many other observers, and in a few months the treatment was practically abandoned. The conditions in guinea-pigs on which the discovery was based have since been found not to be of universal occurrence.

Recent results appear to show that the tuberculin reaction (*i.e.*, fever, and local necrosis round tubercular deposits, following injection of tuberculin) is not yet fully understood, for on the one hand other substances besides products of the tubercle bacillus may give rise to similar effects in tubercular animals, and on the other a similar reaction can take place in other diseases besides tuberculosis where there is locally in the body a deposit of new tissue. Matthes has, for instance, found that albumoses and peptones isolated from the ordinary peptic digestion of various albumins give the same reaction in tubercular guinea-pigs. The injection of milk, lactic acid, ricin all give a similar result. Before the discovery of tuberculin, Gamaleia had found that tubercular animals were very susceptible to the toxines of the vibrio Metchnikovi, and later Metchnikoff found that a similar susceptibility existed towards the toxines of the bacillus of fowl cholera. Buchner found that a group of albuminous bodies which he called proteines, and which he extracted from the bodies of the B. anthracis, B. mallei, and B. prodigiosus, produced the tuberculin reaction, and he considered that the active body in tuberculin was probably of the same nature, and had a similar source. There is, however, no evidence that the substances so derived from different bacteria are identical. While the tuberculin reaction has thus been obtained with other bodies besides tuberculin, a similar reaction has taken place when tuberculin has been injected into persons suffering from diseases other than tubercle, *e.g.*, cancer, sarcoma, syphilis. Further investigations on this subject are thus required.

The Toxines of the Tubercle Bacillus.—Koch's work on tuberculin was the first to show that from tubercle cultures substances could be separated the possession by which of a necrotic action on certain tissues was capable of explaining a great pathological feature of tuberculosis. An impulse was thus given to further inquiries as to the action of toxines of the tubercle bacillus. These inquiries were first directed towards finding out what the substance was to which tuberculin owes its action. Hunter showed that tuberculin consisted chiefly of (1) albumoses, chiefly proto- and deutero-albumose, with small quantities of hetero-albumose and a trace of dysalbumose; (2) alkaloidal substances, two of which can be obtained in the form of platinum compounds of their hydrochlorate salts; (3) extractives, mucin, inorganic salts, etc. Hunter prepared two modifications of tuberculin, one of which contained all that could be precipitated by 70 per cent alcohol, and the

other all that was left. Both had remedial actions, but the former, which of course contained a larger proportion of albumoses, produced less fever than the latter. From this fact it appeared that the necrotic action on the tissues and the fever-producing effects were not necessarily caused by the same body in tuberculin. A similar alcoholic precipitate was introduced by Klebs under the name of "tuberculocidin," and by Koch under the name of "purified tuberculin." No improvement in therapeutic effects was obtained by the use of any of these bodies. The most complete analyses of tuberculin were carried out by Kühne. This observer generally confirmed Hunter's results, except that he found peptone also present. He also found an albumose not previously described, and which he named acro-albumose. On subjecting, however, a control flask of uninoculated glycerine bouillon to the same incubation conditions as a similar bouillon infected with tubercle bacilli, he found that the constituents of the former were identical with those of the latter, acro-albumose being also present. The relative proportions of the different constituents varied, but both in this experiment and in others performed with solutions containing the higher albumoses in a pure condition, Kühne found that after the tubercle bacillus had been growing, there was present a larger proportion of the lower albumoses, *i.e.*, those formed just preliminary to the production of peptone. This indicates that the bacillus has a digestive action on albumin. Whether the albumoses thus formed are the toxic bodies in tuberculin is doubtful. Kühne found that all the varieties he isolated gave a tuberculin reaction in tubercular guinea-pigs, so that they might all simply be carriers of the real toxine. This view he corroborated by a further experiment. Tubercle bacilli were grown in a glycerine medium which contained, instead of peptone, leucin, tyrosin, asparagin, etc. Thus no proteid matter was present. The fluid after culture was analysed as before and no albumoses or peptones were found to be present, but only an albuminate. It nevertheless had the same effect on tubercular animals as tuberculin. The

toxines of tubercle are thus possibly not of the nature of albumoses. Of their real nature we are still ignorant. From what is known, it is possible that they do not to any great extent diffuse out into the culture media. It has been found that if tubercle cultures are filtered germ-free the filtrate does not give such a marked tuberculin reaction as the unfiltered fluid. Maragliano has found that such a fluid, however, causes in animals lowering of temperature and sweating, and further that if it is heated at 100° C. it now gives a much more marked tuberculin reaction. From this he infers that there is diffused out into the culture fluid a body allied to the toxalbumins of Brieger and Fraenkel, which is destroyed by heat, and which has a temperature-lowering action. When this body is destroyed in a tubercle filtrate, any intracellular poison which may be present from the maceration of the bodies of the dead bacilli always present in a growing culture, is unantagonised and now gives the usual reaction. It is thus probable that more than one toxic body may be formed by the tubercle bacillus.

The Use of Tuberculin in the Diagnosis of Tuberculosis in Cattle.—This is now the chief use to which tuberculin is put. In cattle, tuberculosis may be present without giving rise to apparent symptoms. It is thus important from the point of view of human infection that an early diagnosis should be made. The method is applied as follows. The animals are kept twenty-four hours in their byres and the temperature is taken every three hours, from four hours before the injection till twenty-four after. The average temperature in cattle is 102.2° F.; 30 to 40 centigrams of tuberculin are injected, and if the animal be tubercular the temperature rises 2° to 3° F. in eight to twelve hours and continues up for ten to twelve hours. Bang, who has worked most at the subject, lays down the principle that the more nearly the temperature approaches 104° F. the more reason for suspicion is there. He gives a record of 280 cases where the value of the method was tested by subsequent *post-mortem* examination. He found that with proper precautions the error was only 3.3 per cent. The method is

largely practised on the Continent, and ought to be more widely applied.

Immunisation against the Tubercle Bacillus: Antitubercular Serum.—Tuberculosis differs from other diseases against which animals can be immunised in that there is no evidence that one attack protects against a second. Further, we have no means of obtaining truly attenuated tubercle bacilli. Many attempts at immunisation have, however, been made. It has been thought by some that the tubercle bacilli from so-called scrofulous glands are less virulent than those say from phthisis, but apparently here sufficient attention has not been paid to the difference of the numbers of bacilli injected in each case, and this appears to be a very important point. Experiments have also been brought forward which appear to show that the injection of bacilli from avian tuberculosis could protect the dog against bacilli derived from man. But these are not yet conclusive. Further, many attempts have been made at immunisation against the tubercle bacillus by the employment of its toxic products. The most successful have been those of Maragliano. We have seen that this author distinguishes between the toxic bodies contained in the bodies of the bacilli (which withstand, unchanged, a temperature of 100° C.) and those secreted into the culture fluid (which are destroyed by heat). The substance used by him for immunising his animals consists of three parts of the former and one of the latter. Commencing with 2 mgrm. of the mixture he increases the dose by 1 mgrm. daily, till a dose of 40 to 50 mgrm. is reached. This latter quantity is injected daily for six months, by which time a high degree of immunity has been reached. The animals employed are the dog, the ass, the horse. The serum obtained from these is capable of protecting healthy animals against an otherwise fatal dose of tuberculin. Further, a relatively much larger dose of the serum will completely prevent tuberculin from causing its specific reaction in tubercular guinea-pigs. Maragliano does not appear to have studied the effects of this serum on tubercular animals, but it has been tried in a great number

of cases of human tuberculosis. Improvement is said to have taken place in a certain proportion, especially of mild cases. Experiments *in vitro* indicate that the serum has a certain effect on the vital activity of the tubercle bacilli inasmuch as they will not grow in it. Whether this amounts to a bactericidal action or not, requires further investigation. Proof is still wanting that Maragliano's serum can protect susceptible animals against the tubercle bacillus or heal tuberculosis in animals.

Active Immunisation by Intracellular Toxines.—Koch has recently (April 1897) published the results of his latest researches on tuberculosis. These start from the familiar fact that in a guinea-pig inoculated with tubercle, and *allowed to die naturally*, though tubercle bacilli are found in the lesions on microscopic examination, it is often impossible to obtain cultures from these lesions. The last stages in the animal's illness are thus apparently due to the absorption of the intracellular poisons, evidence for the existence of which in the bodies of dead tubercle bacilli we have already seen. Immunisation against such poisons would thus apparently be beneficial in cases of tuberculosis. To isolate them is, however, a difficult matter. Tubercle bacilli, according to Koch, are protected against rapid absorption within the body and against the action of chemical solvents outside the body by the presence, in their protoplasm, of two unsaturated fatty acids, one of which is especially insoluble. To these latter the characteristic staining reactions are also probably due. Koch's isolation method was as follows. Bacilli from young virulent cultures were dried *in vacuo*. They were then well rubbed up with an agate pestle and mortar, treated with distilled water and centrifugalised. The clear fluid was decanted, and is called by Koch "tuberculin O." The remaining deposit was again dried, bruised, treated with water, and centrifugalised, the clear fluid being again decanted. This process was repeated with successive residues till, on centrifugalisation, at last no residue remained. All the fluids were then put together, and these form what Koch calls "tuberculin R."

It differs from tuberculin O, and also from tuberculin as originally made, in that it contains the substances present in the bacilli, which are insoluble in glycerine. Tuberculin O produces the tuberculin reaction like the original glycerine extract, but tuberculin R only does so in large doses. The most important difference, however, is that the latter when injected into animals in repeated doses, produces immunity against the original extract, against tuberculin O, and against living and virulent tubercle bacilli. As supplied commercially, each c.c. corresponds to 10 mgrms. of dried bacilli. Immunisation is carried out by hypodermic injection, commencing with doses of $\frac{1}{500}$ mgrm. of the latter, the necessary dilutions being made with .75 per cent sodium chloride solution. The injections are practised every second day till a dose of 20 mgrms. can be tolerated. In this way, Koch succeeded in immunising a number of guinea-pigs so that the injection of virulent tubercle bacilli had no effect. In other cases the disease produced by the latter was much more localised than is usually the case. He also treated guinea-pigs already infected. For the cure of these the treatment had to be commenced within a fortnight of inoculation. In more advanced cases there was a tendency to improvement in the tubercular lesions. In the case of man, it is early cases of tuberculosis which are likely to be most benefited. The cases of phthisis to be treated should be those in which the temperature does not rise above 100.5° F., and no dose must be given which raises the temperature more than half a degree. In such cases, as also in lupus, improvement has been observed, the temperature becoming lower and the weight increased. Unlike ordinary tuberculin, there is with this "residual" tuberculin no local reaction when it is administered as above, and no general bad effects have followed its use. Much further work must of course be done before we can judge of the value of this new departure. The principle involved is the production by means of the intracellular poisons of the tubercle bacillus of an active immunity in the body of an animal already invaded by the bacillus.

Methods of Examination.—(1) *Microscopic examination.* Tuberculosis is one of the comparatively few diseases in which a diagnosis can usually be definitely made by microscopic examination alone. In the case of sputum, one of the yellowish fragments which are often present ought to be selected; dried films are then prepared in the usual way and stained by the Ziehl-Neelsen method (p. 102). In the case of urine or other fluids a deposit should first be obtained by centrifugalising a quantity in a test-tube, or by allowing the fluids to stand in a tall glass vessel (an ordinary burette is very convenient). Film preparations are then made with the deposit and treated as before.

(2) *Inoculation.*—The guinea-pig is the most suitable animal. If the material to be tested is a fluid it is injected subcutaneously; if a solid or semi-solid it is placed in a small pocket in the skin or it may be thoroughly broken up in sterile water or other fluid and the fluid is then injected. By this method, material in which no tubercle bacilli can be found microscopically may sometimes be shown to be tubercular.

(3) *Cultivation.*—Owing to the difficulties this is usually quite impracticable as a means of diagnosis, and it is also unnecessary. The best method to obtain pure cultures is to produce tuberculosis in a guinea-pig by inoculation with tubercular material, and then, killing the animal after five or six weeks, to inoculate tubes of solidified blood serum, under strict aseptic precautions, with portions of the tubercular organs, *e.g.*, the spleen.

CHAPTER X.

GLANDERS.

THE bacillus of glanders (bacillus mallei; Fr., *bacille de la morve;* Ger., *Rotzbacillus*) was discovered by Löffler and Schutz, the announcement of this discovery being made towards the end of 1882. They not only obtained pure cultures of this organism from the tissues in the disease, but by experiments on horses and other animals conclusively established its causal relationship. The disease had for a long time before this discovery been recognised as directly communicable amongst horses, and also to the human subject; various attempts had been made to discover the organism producing it, and even announcements had been made of such discovery, but these are now known to be erroneous. The results of Löffler and Schutz have been fully confirmed. The same organism has also been cultivated from the disease in the human subject, first by Weichselbaum in 1885, who obtained it from the pustules in a case of acute glanders in a woman, and by inoculation on animals obtained results similar to those of Löffler and Schutz.

Within recent years a substance, *mallein*, has been obtained from the cultures of the glanders bacillus by a method similar to that by which tuberculin was prepared, and has been found to produce corresponding effects in animals suffering from glanders to those produced by tuberculin in tuberculous animals.

The Natural Disease.—Glanders chiefly affects the equine species—horses, mules, and asses. Horned cattle, on the other hand, are quite immune, whilst goats and sheep occupy an intermediate position, the former being rather more susceptible and occasionally suffering from the natural disease. It also occurs in some of the carnivora—cats, lions, and tigers in menageries, which animals are infected from the carcases of animals affected with the disease. Many of the small rodents are highly susceptible to inoculation (*vide infra*).

Glanders is also found in man as the result of direct inoculation on some wound of the skin or other part by means of the discharges or diseased tissues of an animal affected, and hence is commonest amongst grooms and others whose work brings them into contact with horses.

In horses the lesions are of two types, to which the names "glanders" proper and "farcy" have been given, though both may exist together. In glanders proper the septum nasi and adjacent parts are chiefly affected, there occurring in the mucous membrane nodules at first firm and of somewhat translucent grey appearance. The growth of these is attended usually by inflammatory swelling and profuse catarrhal discharge. Afterwards the nodules soften in the centre, break down, and give rise to irregular ulcerations. Similar lesions, though in less degree, may be found in the respiratory passages. Associated with these lesions there is usually implication of the lymphatic glands in the neck, mediastinum, etc.; and there may be nodules in the lungs, spleen, liver, etc., which nodules may be of the size of a pea or larger, of greyish or yellow tint, firm or somewhat softened in the centre, and often surrounded with a congested zone. The term "farcy" is applied to the affection of the superficial lymphatic vessels and glands, which is specially seen where infection takes place through an abrasion of the skin, such as is often produced by the rubbing of the harness. The lymphatic vessels become irregularly thickened, so as to appear like knotted cords, and the lymphatic glands associated become enlarged and

firm, though suppurative softening usually follows, and there may be ulceration. These thickenings are often spoken of as farcy buds and farcy pipes. In farcy also, secondary nodules form, and internal organs and the nasal mucous membrane may be thus affected. In the ass the disease runs a more acute course than in the horse.

In man the disease is met with in two forms, an acute and a chronic, though intermediate forms also occur, and chronic cases may take on the characters of the acute disease. The site of inoculation is usually on the hand or arm, by means of some scratch or abrasion, or possibly along a hair follicle, sometimes on the face, and occasionally on the mucous membrane of the mouth, nose, or eye. In the *acute* form there appears at the site of inoculation inflammatory swelling, attended often with spreading redness, and the lymphatics in relation to the part also become inflamed, the appearances being those of a "poisoned wound." These local changes are soon followed by marked constitutional disturbance, and by an eruption on the surface of the body, at first papular and afterwards pustular, and later there may be in the subcutaneous tissue and muscles larger masses which soften and suppurate, the pus being often mixed with blood, and suppuration may occur in the joints. In some cases the nasal mucous membrane may be secondarily infected, and thence inflammatory swelling may spread to the tissues of the face; in others it remains free. The patient usually dies in two or three weeks, sometimes sooner, with the symptoms of rapid pyæmia. In addition to the lesions mentioned there may be foci, usually suppurative, in the lungs (attended often with pneumonic consolidation), in the spleen, liver, bone-marrow, salivary glands, etc. In the *chronic* form the local lesion results in the formation of an irregular ulcer with thickened margins and sanious, often foul, discharge. The ulceration spreads deeply as well as superficially, and the thickened lymphatics have a great tendency to ulcerate also, though the lymphatic system is not so prominently affected as in the horse. Deposits form also in the sub-

cutaneous tissue and muscles, and the mucous membrane may become affected. The disease often runs a very chronic course, lasting for months, and recovery may occur, though, on the other hand, the disease may take on a more acute character and rapidly lead to a fatal result.

The Glanders Bacillus—*Microscopical Characters.*—The glanders bacilli are minute rods, straight or slightly curved, with rounded ends, and about the same length as tubercle bacilli, but distinctly thicker (Fig. 62). They show, however, considerable variations in size and in appearance, and their protoplasm is often broken up into a number of deeply-stained portions with unstained intervals between. Sometimes the unstained parts are oval or rounded in shape, and resemble spores. These characters are seen both in the tissues and in cultures, but, as in the case of many organisms, irregularities in form and size are more pronounced in cultures (Fig. 63). Occasionally short filamentous forms 8 to 12 μ in length are met with, but these are on the whole rare, most being in the form of single short rods. They are non-motile.

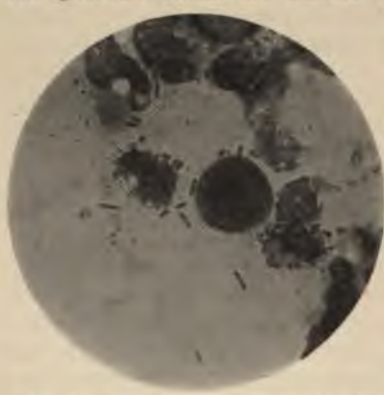

FIG. 62.—Glanders bacilli amongst broken-down cells. Film preparation from a glanders nodule in a guinea-pig.
Stained with weak carbol-fuchsin. × 1000.

In the tissues they usually occur irregularly scattered amongst the cellular elements; a few may be contained within leucocytes and connective tissue corpuscles, but the position of most is extracellular. They are most abundant in the acute lesions, in which they may be found in considerable numbers; but in the chronic nodules, especially

when softening has taken place, they are few in number, and it may be impossible to find any in sections. They have less powers of persistence, and disappear in the tissues much more quickly than tubercle bacilli.

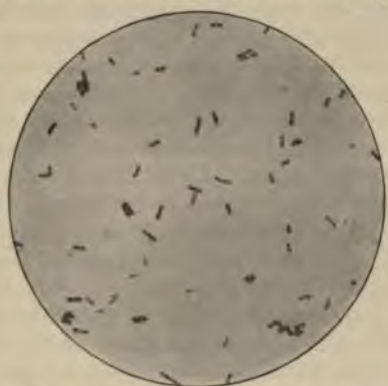

FIG. 63.—Glanders bacilli, from a pure culture on glycerine-agar. Stained with carbol-fuchsin and partially decolorised to show segmentation of protoplasm. × 1000.

There has been dispute as to whether or not they contain spores. Some consider certain of the unstained portions to be of that nature, and it has been claimed that these can be stained by the method for staining spores (Rosenthal). But it is very doubtful that such is the case; the appearances correspond rather with mere breaks in the protoplasm, such as are met with in many other bacilli which do not contain spores, and the comparatively low powers of resistance of glanders bacilli containing these so-called spores is strongly against their being of that nature. The powers of resistance is after all the important practical point.

Staining.—The glanders bacillus differs widely from the tubercle bacillus in its staining reactions. It stains with simple watery solutions of the basic stains, but somewhat faintly (better when an alkali or a mordant, such as carbolic acid, is added), and even when deeply stained it readily loses the colour when a decolorising agent such as alcohol is applied. The stain employed ought therefore to be pretty powerful and preferably such as not to overstain much, and a weak decoloriser should be used. Löffler and Schutz recommended staining of sections in an alkaline solution of methylene-blue for five minutes and then decolor-

ising for a few seconds in water, 10 c.c., to which were added ten drops of a concentrated solution of sulphurous acid and one drop of a 5 per cent solution of oxalic acid. We have, however, obtained the best results by carbol-thionin-blue (p. 98), and we prefer to dehydrate by the aniline-oil method. In film preparations of fresh glanders nodules the bacilli can be readily found by staining with any of the ordinary combinations, *e.g.*, carbol-thionin-blue or weak carbol-fuchsin. By using a stain of suitable strength no decolorising agent is necessary, the film being simply washed in water, dried, and mounted. Gram's method is quite inapplicable, the glanders bacilli rapidly losing the stain in the process.

Cultivation.—(For the methods of separation *vide infra.*) The glanders bacillus grows readily on most of the ordinary media, but a somewhat high temperature is necessary, growth taking place most rapidly at 35° to 37° C., and though a certain amount of growth occurs down to 21° C., a temperature above 25° C. is always desirable.

On *agar* and *glycerine-agar* in stroke cultures growth appears along the line as a uniform streak of greyish-white colour and somewhat transparent appearance, with moist-looking surface, and when touched with a needle is found to be of rather slimy consistence. Later it spreads laterally for some distance, and the layer becomes of slightly brownish tint. On *serum* the growth is somewhat similar but more transparent, the separate colonies being in the form of round and almost clear drops. In sub-cultures on these media at the body temperature growth is visible within twenty-four hours, but when fresh cultures are made from the tissues it is not visible till the second day. Serum, however, is much more suitable for cultivating from the tissues than the agar media, on which it is sometimes difficult to obtain growth.

In *broth*, growth forms at first a uniform turbidity, but soon settles to the bottom, and after a few days forms a pretty thick flocculent deposit of slimy and somewhat tenacious consistence.

On *potato* the glanders bacillus flourishes well and produces a characteristic appearance, incubation at a high temperature, however, being necessary. If inoculation is made to potato from another medium, growth proceeds rapidly, and on the third day has usually formed a transparent layer of slightly yellowish tint, like clear honey in appearance. On subsequent days, the growth still extends and becomes darker in colour and more opaque, till about the eighth day it has a reddish-brown or chocolate colour, while the potato at the margin of the growth often shows a greenish-yellow staining. The characters of the growth on potato along with the microscopical appearances are quite sufficient to distinguish the glanders bacillus from every other known organism (sometimes the cholera organism and the B. pyocyaneus produce a somewhat similar appearance, but they can be readily distinguished by their other characters). The potato is also a suitable medium for starting cultures from the tissues, in this case minute transparent colonies being visible on the third day and afterwards presenting the appearances just described.

Powers of Resistance.—The glanders bacillus is not killed at once by drying, but usually loses its vitality after fourteen days in the dry condition, though sometimes it lives longer. It is not quickly destroyed by putrefaction, as glanders bacilli have been found to be still active after remaining two or three weeks in putrefying fluids. In cultures the bacilli retain their vitality for three or four months, if, after growth has taken place, they be kept at the temperature of the room; on the other hand, they are often found to be dead at the end of a month when kept constantly at the body temperature. They have comparatively feeble resistance to heat and antiseptics. Löffler found that they were killed in ten minutes in a fluid kept at 55° C., and in two to three minutes by a 5 per cent solution of carbolic acid. Boiling water and the ordinarily used antiseptics are very rapid and efficient disinfectants.

We may summarise the characters of the glanders bacillus by saying that in its morphological characters it

resembles somewhat the tubercle bacillus, but is thicker, and differs widely from it in its staining reactions. For its cultivation the higher temperatures are necessary, and the growth on potato presents most characteristic features.

Experimental Inoculation.—Subcutaneous injection in horses of pure cultures of the glanders bacillus reproduces all the important features of the disease. This fact was established at a comparatively early date by Löffler and Schutz, who, after one doubtful experiment, successfully inoculated two horses in this way, the cultures used having been grown for several generations outside the body. In a few days boggy swellings formed at the sites of inoculation, and later broke down into unhealthy-looking ulcers. There was the usual involvement of the lymphatic vessels and glands, the latter becoming swollen to the size of pigeons' eggs, and symptoms due to affection of the nasal mucous membrane also appeared after some time, there being the characteristic discharge. One of the animals died; after a few weeks the other, showing symptoms of cachexia, was killed. In both animals there were found *post mortem*, in addition to ulcerations on the surface with involvement of the lymphatics, nodules in the lungs, softened deposits in the muscles, and also affection of the nasal mucous membrane, with nodules, and irregular ulcerations. The ass is even more susceptible than the horse, the disease in the former running a more rapid course, but with similar lesions. The ass can be readily infected by scarification and inoculation with glanders secretion, etc. (Nocard).

Of small animals, field-mice and guinea-pigs are the most susceptible. Strangely enough, house-mice and white mice enjoy an almost complete immunity. In field-mice subcutaneous inoculation is followed by a very rapid disease, usually leading to death within eight days, the organisms becoming generalised and producing numerous minute nodules, especially in the spleen, lungs, and liver. In the guinea-pig the disease is less acute, though secondary nodules in internal organs are usually present in considerable numbers. At the site of inoculation an inflammatory

swelling forms, which soon softens and breaks down, leading to the formation of an irregular crateriform ulcer with indurated margins. The lymphatic vessels become infiltrated, and the corresponding lymphatic glands become enlarged to the size of peas or small nuts, softened, and semi-purulent. The animal sometimes dies in two or three weeks, sometimes not for several weeks. Secondary nodules, in varying numbers in different cases, may be found in the spleen, lungs, bones, nasal mucous membrane, testicles, ovaries, etc.; in some cases a few nodules are found in the spleen alone. Intraperitoneal injection in the male guinea-pig is followed, as pointed out by Straus, by a very rapid and semi-purulent affection of the tunica vaginalis, shown during life by a great swelling and redness of the testicles, which may be noticeable in two or three days. By this method there occur also extensive deposits in the omentum, and numerous small nodules on the surface of the peritoneum. Minute nodules may be present in the various organs, but they are often invisible to the naked eye.

Rabbits are less susceptible than guinea-pigs, and the effect of subcutaneous inoculation is somewhat uncertain. Sometimes only a local lesion results, sometimes a generalised affection.

Action on the Tissues.—From the above facts it will be seen that in many respects glanders presents an analogy to tubercle as regards the general characters of the lesions and the mode of spread. In the guinea-pig, for example, there are in both diseases a local swelling, an implication of lymphatics in connection with the part, and, lastly, a spread to internal organs and other parts by means of the blood vessels. When the tissue changes in the two diseases are compared, certain differences are found. The glanders bacillus causes a more rapid and more marked inflammatory reaction. There is more leucocytic infiltration and less proliferative change which might lead to the formation of epithelioid cells. Thus the centre of an early glanders nodule shows a dense aggregation of

leucocytes, many of which are of the multinucleated type, and have recently emigrated from the vessels, whilst the tissue elements between may be more or less degenerating, or may show proliferative changes. And further, the inflammatory change may be followed by suppurative softening of the tissue, especially in certain situations, such as the subcutaneous tissue and lymphatic glands. The nodules, therefore, in glanders, as Baumgarten puts it, occupy an intermediate position between miliary abscesses and tubercles. The diffuse coagulative necrosis and caseation which are so common in tubercle do not occur to the same degree in glanders, and typical giant cells are not formed. The nodules in the lungs show leucocytic infiltration and thickening of the alveolar walls, whilst the vesicles are filled with catarrhal cells; *i.e.*, there is reaction both on the part of the connective tissue, and of the endothelium of the air vesicles, whilst at the periphery of the nodules, fibrous tissue growth is present in proportion to their age. The tendency to spread by the lymphatics is always a well-marked feature, and when the bacilli gain entrance to the blood-stream, they soon settle in the various tissues and organs. Accordingly, even in acute cases it is usually quite impossible to find the bacilli in the circulating blood, though sometimes they have been found. It is an interesting fact, shown by observations of the disease both in the human subject and in the horse, as well as by experiments on guinea-pigs, that the mucous membrane of the nose may become infected by means of the blood—another example of the tendency of organisms to settle in special sites.

Mode of Spread. — Glanders usually spreads from a diseased animal by direct contagion with the discharge from the nose or from the sores, etc. So far as infection of the human subject goes, no other mode is known. There is no evidence that the disease is produced in man by inhalation of the bacilli in the dried condition. Some authorities consider that pulmonary glanders may be produced in this way in the horse, whilst others maintain that in

all cases there is first a lesion of the nasal mucous membrane or of the skin surface, and that the lung is affected secondarily. Babes, however, found that the disease could be readily produced in susceptible animals by exposing them to an atmosphere in which cultures of the bacillus had been pulverised. He also found that inunction of the skin with vaseline containing the bacilli might produce the disease, the bacilli in this case entering along the hair follicles.

Mallein and its Preparation.—Mallein is obtained from cultures of the glanders bacillus grown for a suitable length of time, and, like tuberculin, is really a mixture comprising (1) substances in the bodies of the bacilli and (2) their soluble products, not destroyed by heat, along with substances derived from the medium of growth. It was at first obtained from cultures on solid media by extracting with glycerine or water, but is now usually prepared from cultures in glycerine bouillon. Such a culture, after being allowed to grow for three or four weeks, is sterilised by heat either in the autoclave at 115° C. or by steaming at 100° C. on successive days. It is then filtered through a Chamberland filter. The filtrate constitutes fluid mallein. Usually a little carbolic acid (.5 per cent) is added to prevent it from decomposing. Of such mallein 1 c.c is usually the dose for a horse (M'Fadyean). Foth has prepared a dry form of mallein by throwing the filtrate of a broth culture, evaporated to one-tenth of its bulk, into twenty-five or thirty times its volume of alcohol. A white precipitate is formed, which is dried over calcium chloride and then under an air-pump. A dose of this dry mallein is .05 to .07 gram.

The use of Mallein as a means of Diagnosis.—In using mallein for the diagnosis of glanders, the temperature of the animal ought to be observed for some hours beforehand, and, after subcutaneous injection of a suitable dose, it is taken at suitable intervals,—according to M'Fadyean at the sixth, tenth, fourteenth, and eighteenth hours afterwards, and on the next day. Here both the local reaction and the temperature are of importance. In a glandered animal, at the site of inoculation there is a somewhat painful local swelling which reaches a diameter of five inches at least, the maximum size not being attained until twenty-four hours afterwards. The temperature rises 1.5° to 2° F., or more, the maximum generally occurring in eight to sixteen hours. If the temperature never rises as much as 1½°, the reaction is considered doubtful. In the negative reaction given by an animal free from glanders, the temperature often rises 1°, the local swelling reaches the diameter of three inches at most, and has much diminished at the end of twenty-four hours. In the case of dry mallein, local reaction is less marked. Veterinary authorities are practically unanimous as to the great value of the mallein test as a means of diagnosis.

Methods of Examination.—Microscopic examination in a case of suspected glanders will at most reveal the presence of bacilli corresponding in their characters to the glanders bacillus. An absolute diagnosis cannot be made by this method. Cultures may be obtained by making successive strokes on blood serum or on glycerine-agar (preferably the former), and incubating at 37° C. The colonies of the glanders bacillus do not appear till two days after. This method often fails unless a considerable proportion of the glanders bacilli are present. Another method is to dilute the secretion or pus with sterile water, to varying degrees, and then to smear the surface of potato with the mixture, the potatoes being incubated at the above temperature. The colonies on potato do not appear till the third day. The most certain method, however, is by inoculation of a guinea-pig, either by subcutaneous or intraperitoneal injection. By the latter method, as above described, lesions are much more rapidly produced, and are more characteristic. If, however, there have been other organisms present, the animal may die of a septic peritonitis, though even in such a case the glanders bacilli will be found to be more numerous in the tunica vaginalis, and may be cultivated from this situation.

CHAPTER XI.

LEPROSY.

Leprosy is a disease of great interest, alike in its clinical and pathological aspects; and also from the bacteriological point of view it presents some striking peculiarities. The invariable association of large numbers of characteristic bacilli with all the leprous lesions is a well-established fact, and yet, so far, attempts to cultivate the bacilli outside the body, or to produce the disease experimentally in animals, have been attended with failure. Leprosy, so far as definite knowledge carries us, is a disease which is confined to the human subject, but it has a very wide geographical distribution. It occurs in certain parts of Europe—Norway, Russia, Greece, etc. It is commonest, however, in Asia, occurring in Syria, Persia, etc., and also has a wide distribution in Africa, being especially found along the coast. It is also found in the Pacific Islands, in the warmer parts of North and South America, and also to a small extent in the northern part of North America. In all these various regions the disease presents the same general features, and the study of its pathological and bacteriological characters, wherever such has been carried on, has revealed similar facts.

Pathological Changes.—Leprosy is characteristically a chronic disease in which there is a great amount of tissue change, with comparatively little necessary impairment of the general health. In other words, the local irritative

effects of the bacilli are well marked, often extreme, whilst the toxic phenomena are proportionately at a minimum.

There are two chief forms of leprosy. The one, usually called the tubercular form—*lepra tuberosa* or *tuberculosa*—is characterised by the growth of granulation tissue in a nodular form or as a diffuse infiltration in the skin, in mucous membranes, etc., which often leads to great disfigurement. In the other form, the anæsthetic,—maculo-anæsthetic of Hansen and Looft—the outstanding changes are in the nerves, leading ultimately to destruction of nerve fibres with consequent anæsthesia, paralysis of muscles, and trophic disturbances.

In the *tubercular* form the disease usually starts with the appearance of erythematous patches attended by a small amount of fever, and these are followed by the development of small nodular thickenings in the skin, especially of the face, of the backs of hands and feet, and of the extensor aspects of arms and legs. These nodules enlarge and produce great distortion of the surface, so that, in the case of the face, an appearance is produced which has been described as "leonine." The thickenings occur chiefly in the cutis, to a less extent in the subcutaneous tissue. The epithelium often becomes stretched over them, and an oozing surface becomes developed, or actual ulceration may occur. The cornea and other parts of the eye, the mucous membrane of the mouth, larynx, and pharynx may be the seat of similar nodular deposits. There may also be lesions in internal organs, the spleen, liver, and testicles being most commonly affected, the condition consisting of a slight fibrosis with small nodular thickenings at places, which chiefly follow the lines of the blood vessels. Less frequently, lesions are present in other organs. In all situations the change is of the same nature,—a sort of chronic inflammatory condition attended by abundant formation of granulation tissue which may be of a nodular character, or more diffuse in its arrangement. In this tissue a large proportion of the cellular elements are of rounded or oval shape, like large uninucleated leucocytes, and a number of these may be of

comparatively large size, and may show vacuolation of their protoplasm and a vesicular type of nucleus. These are often known as "lepra cells." Amongst the cellular elements there is a varying amount of stroma, which in the earlier lesions is scanty and delicate, but in the old lesions may become very dense. Periarteritis is a common feature, and very frequently the superficial nerves become involved in the nodules and undergo atrophy. The tissue in the leprous lesions is comparatively vascular, at least when young, and, unlike tubercular lesions, never shows caseation. Some of the lepra cells may contain several nuclei, but we do not meet with cells resembling in their appearance tubercle giant cells, nor does an arrangement like that in tubercle follicles occur.

In the *anæsthetic* form the lesion of the nerves is the outstanding feature. These are the seat of diffuse infiltrations which lead to the destruction of the nerve fibres. In the earlier stages, in which the chief symptoms are pains along the nerves, there occur patches on the skin, often of considerable size, the margin of which shows a somewhat livid congestion. Later, these patches become pale in the central parts, and the periphery becomes pigmented. There then follow remarkable series of trophic disturbances in which the skin, muscles, and bones are especially involved. The skin often becomes atrophied, parchment-like, and anæsthetic, and frequently is the seat of trophic changes, such as the formation of pemphigoid bullæ. The bones become atrophied, and, owing to the irregular affection of the muscles, great distortion of the extremities may result. Partly owing to injury to which the feet and arms are liable from their anæsthetic condition, and partly owing to trophic disturbances, necrosis and separation of parts are liable to occur. In this way great distortion results. The lesions in the nerves are of the same nature as those described above, that is, they are the result of a chronic inflammatory process, but the granulation tissue produced is less in amount, and has a greater tendency to undergo cicatricial contraction. This is to be associated

with the fact, to be afterwards stated, that the bacilli are present in fewer numbers.

Bacillus of Leprosy.—This bacillus was first observed in leprous tissues by Hansen in 1871, and was the subject of several communications by him in 1874 and later. Further researches, first by Neisser in 1879, and afterwards by observers in various parts of the world, agreed in their main results, and confirmed the accuracy of Hansen's observations. The bacilli as seen in scrapings of ulcerated leprous nodules, or in sections, have the following characters. They are thin rods of practically the same size as tubercle bacilli, which they also resemble both in appearance and in staining reaction. They are straight or slightly curved, and usually occur singly, or two may be attached end to end; but they do not form chains. When stained they may have a uniform appearance, or the protoplasm may be fragmented, so that they appear like short rows of cocci darkly stained alternating with unstained points. They often appear tapered at one or both extremities; occasionally there is small club-like swelling. Bacilli, partially broken down, are also seen. They take up the basic aniline stains rather more readily than tubercle bacilli, but in order to stain them deeply a powerful stain, such as carbol-fuchsin, is necessary. When stained, they strongly resist decolorising, though they are more easily decolorised than tubercle bacilli. The best method is to stain with carbol-fuchsin as for tubercle bacilli, but to use a weaker solution of sulphuric acid, say 5 per cent, in decolorising; in the case of films and thin sections, decolorising with such a solution for fifteen seconds is usually sufficient. Thereafter the tissues are coloured by a contrast stain, such as a watery solution of methylene-blue (*vide* p. 102). The bacilli are also readily stained by Gram's method. Regarding the presence of spores practically nothing is known, though some of the unstained or stained points may be of this nature. We have, however, no means of testing their powers of resistance. Leprosy bacilli are non-motile.

Position of the Bacilli.—They occur in enormous num-

bers in the leprous lesions, especially in the tubercular form. In fact, so numerous are they that the granulation tissue in sections, properly stained as above, presents quite a red colour under a low power of the microscope. The bacilli occur for the most part within the protoplasm of the round cells of the granulation tissue, and are often so

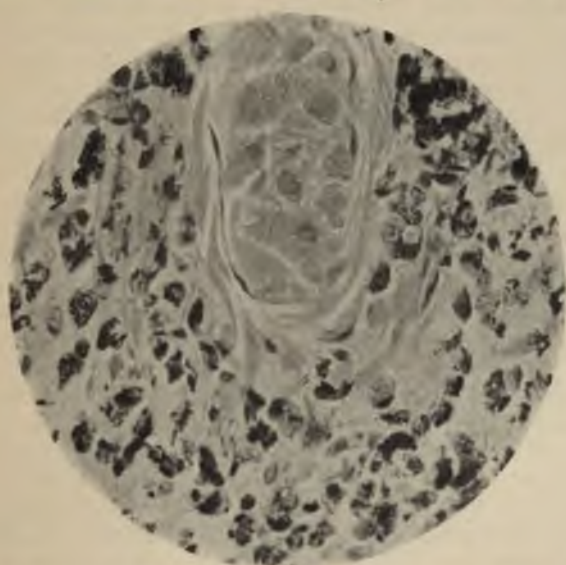

FIG. 64.—Superficial part of leprous skin, showing the cells of the granulation tissue filled with bacilli (stained darkly). In the upper part a process of epithelium is seen.

Paraffin section; stained with carbol-fuchsin and Bismarck-brown. × 500.

numerous that the structure of the cells is quite obscured (Fig. 64). They are often arranged in bundles which contain several bacilli lying parallel to one another, though the bundles lie in various directions (Fig. 65). The appearance thus presented by the cells filled with bacilli is very characteristic. Bacilli are also found free in the lymphatic spaces,

but the greater number are undoubtedly contained within the cells. They are also found in the spindle-shaped connective tissue cells of the granulation tissue, in endothelial cells, and in the walls of blood vessels. They are for the most part confined to the leucocytes and connective tissue elements, but a few may be seen in the hair follicles and

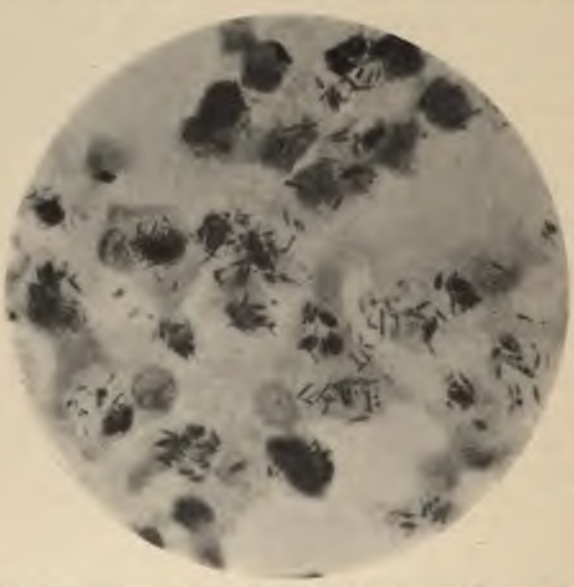

FIG. 65.—High-power view of portion of leprous nodule showing the arrangement of the bacilli within the cells of the granulation tissue. Paraffin section; stained with carbol-fuchsin and methylene-blue. × 1100.

glands of the skin. Occasionally one or two may be found in the surface epithelium, where they probably have been carried by leucocytes, but that position is, on the whole, exceptional. They also occur in large numbers in the lymphatic glands associated with the affected parts. In the internal organs—liver, spleen, etc., when leprous lesions are present the bacilli are also found, though in relatively fewer

numbers. In the sheaths of the nerves in the anæsthetic form they are comparatively few in number, and in the sclerosed tissue it may be impossible to find any. There are few also in the skin patches referred to above as occurring in this form of the disease.

Their spread is chiefly by the lymphatics, though distribution by the blood stream also occurs. They have been said to be found in the blood during the presence of fever and the eruption of fresh nodules, and they have also been observed in the blood vessels *post mortem*, being chiefly contained within leucocytes. Recent observations (*e.g.*, those of Doutrelepont and Wolters) show that the bacilli may be more widely spread throughout the body than was formerly supposed. A few may be detected in some cases in various organs which show no structural change, especially in the capillaries. The brain and spinal cord are practically exempt.

Relations to the Disease.—Attempts to cultivate the leprosy bacilli outside the body have so far been unsuccessful. From time to time announcements of successful cultivations have been made, but one after another has proved to be erroneous. A similar statement may be made with regard to experiments in animals. If a piece of leprous tissue be introduced subcutaneously in an animal, such as the rabbit, a certain amount of induration may take place around it, and the bacilli may be found unchanged in appearance weeks or even months afterwards, but no multiplication of the organisms takes place. The only exception to this statement is afforded by the experiments of Melcher and Orthmann, who inoculated the anterior chamber of the eye of rabbits with leprous material, the inoculation being followed by an extensive growth of nodules in the lungs and internal organs, which they affirmed contained leprosy bacilli. It has been questioned, however, by several authorities whether the organisms in the nodules were really leprosy bacilli, and up to the present we cannot say that there is any satisfactory proof that the disease can be transmitted to any of the lower animals.

It would also appear that the disease is not readily inoculable in the human subject. In a well-known case described by Arning, a criminal in the Sandwich Islands was inoculated in several parts of the body with a leprosy tissue. Two or three years later, well-marked tubercular leprosy appeared and led to a fatal result. This experiment, however, is open to objections, as the individual before inoculation had been exposed to infection in a natural way, having been frequently in contact with lepers. In other cases inoculation experiments on healthy subjects, and inoculations in other parts of leprous individuals have given negative results. It has been supposed by some that the failure to obtain cultures and to reproduce the disease experimentally may be partly due to the bacilli in the tissues being dead. That many of the leprous bacilli are in a dead condition is quite possible, in view of the long period during which dead tubercle bacilli introduced into the tissues of animals retain their form and staining reaction. There is also the fact that from time to time in leprous subjects there occur attacks of a certain amount of fever, which are followed by a fresh outbreak of nodules, and it would appear that at these times especially multiplication of the bacilli takes place more actively.

The facts stated with regard to cultivation and inoculation experiments go to distinguish the leprosy bacillus all the more strongly from other organisms. Some have supposed that leprosy is a form of tubercle, or tubercle modified in some way, but for this there appears to us to be no evidence. Both from the pathological and from the bacteriological point of view the diseases are distinct. It should also be mentioned that tubercle is a not uncommon complication in leprous subjects, in which case it presents the ordinary characters.

The mode by which leprosy is transmitted has been the subject of great controversy, and is one on which authorities still hold opposite opinions. Some consider that it is a hereditary disease, or at least that it is transmitted from a parent to the offspring; others again that it is transmitted by

direct contact. There appears to be no doubt, however, that on the one hand leprous subjects may bear children free from leprosy, and that on the other hand, healthy individuals entering a leprous district may contract the disease, though this rarely occurs. Of the latter occurrence there is the well-known instance of Father Damien, who contracted leprosy after going to the Sandwich Islands. In view of the fact that we must regard the bacillus as the cause of the disease, it is highly probable that in certain conditions it may be transmitted by direct contact, though its contagiousness is not of a high order.

In leprosy, therefore, there is an organism which is invariably present in the disease, and has a special relation to the changes in the tissues. This organism can be distinguished from all other known organisms, and is found in no other condition. Further, all the tissue changes in leprosy can be readily explained by the presence of a low form of irritation, such as is afforded by this organism. The evidence stated must be accepted as to its being the cause of the disease, though absolute proof is still wanting owing to failure to cultivate the organism outside the body.

Methods of Diagnosis.—Film preparations should be made with the discharge from any ulcerated nodule which may be present, or from the scraping of a portion of excised tissue, and should be stained as above described. The presence of large numbers of bacilli situated within the cells and giving the staining reaction of leprosy bacilli, is conclusive. It is more satisfactory, however, to make microscopic sections through a portion of the excised tissue, when the structure of the nodule and the arrangement of the bacilli can be readily studied. The points of difference between leprosy and tubercle have already been stated, and in most cases there is really no difficulty in distinguishing the two conditions.

CHAPTER XII.

ACTINOMYCOSIS.

Actinomycosis is a disease of special interest, inasmuch as it is the most important example of a microbic affection in which the parasite belongs to a higher order, and presents greater complexity of form, than the ordinary bacteria. It is related, by the characters of the pathological changes, to the diseases which have been described.

The disease affects man in common with certain of the domestic animals, though it is more frequent in the latter, especially in oxen, swine, and horses. The parasite was first discovered in the ox by Bollinger, and described by him in 1877, the name *actinomyces* or *ray-fungus* being from its appearance applied to it by the botanist Harz. In 1878 Israel described the parasite in the human subject, and in the following year Ponfick identified it as being the same as that found in the ox. Since that time a large number of cases have been observed in the human subject, the result of investigation being to show that it affects man much more frequently than was formerly supposed. The disease in man is characterised by chronic suppurative processes, which often extend to internal organs, producing a sort of chronic pyæmia, and the disease in the pig is of somewhat similar nature. In the ox, on the other hand, and also in the horse, the lesions are characterised by an abundant formation of granulation tissue, often resulting in tumour-like masses of considerable size.

Naked-eye Characters of the Parasite.—The actinomyces grows in the tissues in the form of little round masses or colonies, which, when fully developed, are easily visible to the naked eye, the largest being about the size of a small pin's head, whilst all sizes below this may be found. When suppuration is present, they lie free in the pus; when there is no suppuration, they are embedded in the granulation tissue, but are usually surrounded by a zone of softer tissue. They may be transparent or jelly-like, or they may be opaque and of various colours—white, yellow, greenish, or almost black. The appearance depends upon their age and also upon their structure, the younger colonies being more or less transparent, the older ones being generally opaque. Their colour is modified by the presence of pigment and by degenerative change, which is usually accompanied by a yellowish coloration. They are generally of soft, sometimes tallow-like, consistence, though sometimes in the ox they are gritty, owing to the presence of calcareous deposit. They may be readily found in the pus by spreading it out in a thin layer on a glass slide and holding it up to the light. They are sometimes described as being always of a distinctly yellow colour, but this is only occasionally the case; in fact, in the human subject they occur much more frequently as small specks of semi-translucent appearance, and of greenish-grey tint.

Microscopical Characters.—There is still dispute as to the exact botanical position of the actinomyces, though most authorities regard it as a pleomorphous bacterium belonging to the streptothrix forms (p. 19). This view appears to us to be the correct one. In the colonies, as they grow in the tissues, three morphological elements may be described, namely, filaments, cocci, and clubs.

1. The *filaments* are comparatively thin, measuring about .5 μ in diameter, but they are often of great length. They are composed of a central protoplasm enclosed by a sheath. The latter, which is most easily made out in the older filaments with granular protoplasm, sometimes contains granules of dark pigment. In the centre of the colony the

filaments interlace with one another, and form an irregular network which may be loose or dense; at the periphery they are often arranged in a somewhat radiating manner, and run outwards in a wavy or even spiral course. They also show branching, a character which at once distinguishes them from the ordinary bacteria. Many colonies are

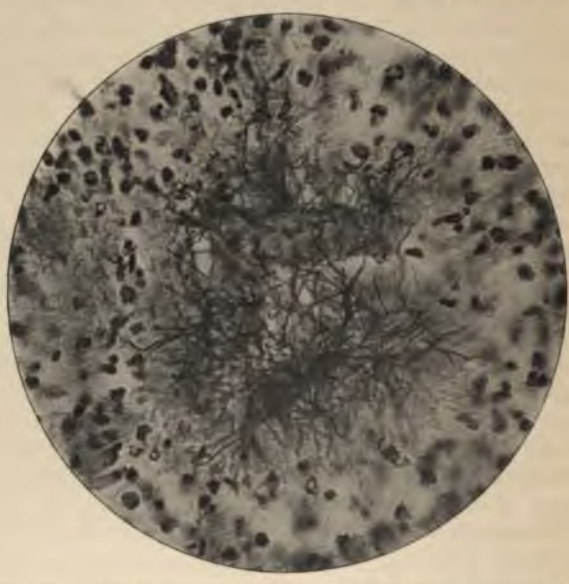

FIG. 66. — Actinomycosis of human liver, showing a colony of the parasite composed of a felted mass of filaments surrounded by pus. Paraffin section; stained by Gram's method and with safranin. × 500.

chiefly constituted by filaments arranged as described (Fig. 66). The filaments usually stain uniformly in the younger colonies, but some, especially in the older colonies, show deficiencies in the protoplasm, which may be regularly segmented so as to give the appearance of a chain of bacilli. Short bacillary forms may at places be seen lying closely packed in masses. In other filaments the protoplasm may

be broken up into little rounded bodies like cocci, so as to give the appearance of a streptococcus, though the sheath enclosing them may generally be distinguished. Sometimes these spherical bodies come to lie free.

2. *Cocci.*—The formation of these from filaments has already been described, but occasionally young colonies have been found to be largely composed of them, so that, apparently, they multiply by division. Their nature has been much discussed, some observers looking upon them as spores, though for this there does not appear to be sufficient evidence. It is better to use the term cocci, and to consider them as constituting a stage in the growth of the parasite in certain conditions. If the view that the parasite is a streptothrix is correct, they are probably to be regarded as *conidia.* Probably both they and the short bacillary forms can be formed from the filaments, and in turn can develop again into the longer threads. The filaments and cocci are readily stained by Gram's method.

3. *Clubs.*—These are elongated pear-shaped bodies which are seen at the periphery of the colony, and are formed by a sort of hyaline swelling of the sheath around the free extremity of a filament (Fig. 67). They are usually homogeneous and structureless in appearance. In the human subject the clubs are often comparatively fragile structures which are easily broken down, and may sometimes be dissolved in water. Sometimes they are well seen when examined in the fresh condition, but in hardened specimens are no longer distinguishable. In specimens stained by Gram's method they are not coloured by the violet, but take readily a contrast stain, such as picric acid, rubin, etc.; sometimes a darkly-stained filament can be seen running for a distance in the centre, and may have a knob-like extremity. In many of the colonies in the human subject the clubs are absent. In the ox, on the other hand, where there are much older colonies, the clubs are practically always present, and are more highly resistant structures than those in the human subject usually are. They often

form a dense fringe around the colony, and when stained by Gram's method retain the violet stain. They have, in fact, undergone some further chemical change which produces the altered staining reaction. Clubs showing intermediate staining reaction have been described by M'Fadyean. The view that the clubs are organs of fructification has been

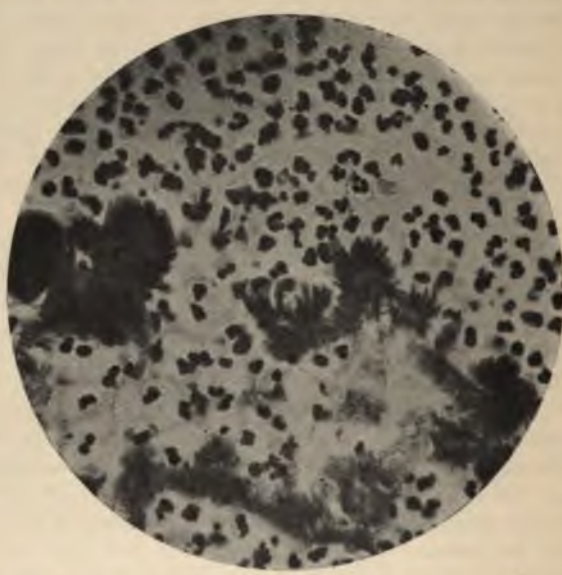

FIG. 67. — Actinomyces in human kidney, showing clubs radially arranged and surrounded by pus. The filaments had practically disappeared.

Paraffin section; stained with hæmatoxylin and rubin. × 500.

abandoned by most authorities, and there appears to us little evidence in support of it.

Structural Arrangement of the Colonies.—The arrangement in the human subject differs somewhat from that in the ox, the difference being chiefly due to the fact that in the latter the disease is more chronic, and most of the

colonies are usually found to be in an old and somewhat degenerated condition.

In the human subject, the colony is generally a ball of interlacing filaments, whilst clubs may be present at the periphery, or may be absent. There is often at one side a part which is so dense that its structure cannot be made out, and this dense part may grow round the colony so as to form a sort of hollow sphere, from the outer surface of which filaments radiate outward for a short distance. In the dense parts many cocci and bacillary forms are often present. Between the filaments there is a homogeneous or slightly granular ground substance, and this may form a narrow zone around the colony, especially when it is growing quickly. The older colonies show irregularity of structure, and the filaments may be much broken up.

In the ox the clubs are usually the most prominent feature; in most of the colonies the filaments have disappeared in part, and in some it may be impossible to find any. Even the clubs may be partly broken down. This condition is also sometimes found in old colonies in the human subject. In the ox the colonies may have undergone calcification. The growth of the parasite and progress of the disease are therefore slower than in man, and it is only in parts where the disease has recently appeared that filamentous forms are well seen.

Tissue Lesions.—In the human subject the parasite produces by its growth a chronic inflammatory change, which usually ends in a suppuration which slowly spreads. In some cases there is a comparatively large production of granulation tissue, with only a little softening in the centre, so that the mass feels solid. This condition is sometimes found in the subcutaneous tissue, especially when the disease has not advanced far, and also in dense fibrous tissue. In most cases, however, and especially in internal organs, suppuration is the outstanding feature. In an organ such as the liver, multiple foci of suppuration are seen at the spreading margin of the disease, presenting a honeycomb appearance which is somewhat characteristic,

and the colonies of the parasite can be seen lying in the pus. Microscopically these abscesses show collections of ordinary pus corpuscles, in which colonies of the parasite lie, and which are enclosed by strands of granulation tissue. Later the abscesses become confluent, and form large areas of suppuration. The pus in these abscesses is usually of greenish-yellow colour, and of somewhat slimy character.

In cattle the tissue reaction is more of a formative type, there being abundant growth of granulation tissue around the parasite, which may lead to the formation of large tumour-like masses, usually of irregularly nodulated character. The cells immediately around the colonies are usually irregularly rounded, or may even be somewhat columnar in shape, whilst farther out they become spindle-shaped and concentrically arranged. It is not uncommon to find leucocytes or granulation tissue invading the substance of the colonies, and portions of the parasite, etc., may be contained within leucocytes or within small giant-cells which are sometimes present. A similar invasion of old colonies by leucocytes is sometimes seen in human actinomycosis. The spread of the disease is usually more rapid in the human subject, and this is associated with abundant growth of the parasite in the filamentous form, and with much suppuration.

Origin and Distribution of Lesions.—The lesions in the human subject may occur in almost any part of the body, the paths of entrance being very various. In many cases the entrance takes place in the region of the mouth—probably around a decayed tooth—by the crypts of the tonsil, or by some abrasion. There is reason for believing that growth often takes place first in such situations, and afterwards the parasite invades the tissues. Swelling and suppuration may then follow in the vicinity, and the disease may spread in various directions. It may attack the periosteum of the jaw or the vertebræ, producing caries or necrosis, or the pus may spread deeply in the tissues of the neck, and may even pass into the mediastinum. Occasion-

ally the parasite may enter the tissues from the œsophagus. In a considerable number of cases the primary lesion is in some part of the intestine, generally of the large intestine. The parasite penetrates the wall of the bowel, and may be found deeply between the coats, surrounded by purulent material. The affection is followed by ulceration, and sometimes by a considerable amount of necrosis. Thence it may spread to the peritoneum or to the extraperitoneal tissue, the retro-cæcal connective tissue and that around the rectum being not uncommonly seats of suppuration produced in this way. A peculiar affection of the intestine has been described, in which slightly raised plaques are found both in the large and small intestines, these plaques being composed almost exclusively of masses of the actinomyces along with epithelial cells. This, however, is a very rare condition. The path of entrance may also be by the respiratory passages, the primary lesion being pulmonary or peribronchial; and extensive suppuration in the lungs may result. Infection may also occur by the skin surface, and lastly, by the female genital tract, as in a case recorded by Sir T. Grainger Stewart and one of us, in which both ovaries and both Fallopian tubes were affected.

In actinomycosis the abscesses are apt to burrow in various directions, and may open externally, leading to chronic sinuses, which discharge pus in which the parasite may be found. When the parasite has invaded the tissues by any of these channels, secondary or "metastatic" abscesses may occur in internal organs. The liver is the organ most frequently affected, though abscesses may occur in the lungs, brain, kidneys, etc. In such cases the spread takes place by the blood stream, and it is possible that leucocytes may be the carriers of the infection, as it is not uncommon to find leucocytes in the neighbourhood of a colony containing small portions of the filaments in their interior.

In the ox, on the other hand, the disease usually remains quite local, or spreads by continuity. It may produce tumour-like masses in the region of the jaw or neck, or it may specially affect the palate or tongue, in the latter pro-

ducing enlargement and induration, with nodular thickening on the surface—the condition known as "woody tongue."

Source of the Parasite.—There is a considerable amount of evidence to show that outside the body the parasite grows on grain, especially on barley. Both in the ox and in the pig the parasite has been found growing around fragments of grain embedded in the tissues. There are besides, in the case of the human subject, a certain number of cases in which there was a history of penetration of a mucous surface by a portion of grain, and in a considerable proportion of cases the patient has been exposed to infection from this source. The position of the lesions in cattle is also in favour of such a view. The conditions of growth outside the body in a natural condition are, however, not known, nor has the parasite been cultivated from any source outside the body.

A B

FIG. 68.—Cultures of the actinomyces on glycerine-agar, of about three weeks' growth; showing the appearances which occur. The growth in A is at places somewhat corrugated on the surface. Natural size.

Cultivation (for methods of isolation see later).—The actinomyces can be cultivated outside the body, and the disease has been experimentally reproduced in animals. It grows on a variety of media, though on all, its rate of growth is somewhat slow. Growth

takes place at the ordinary room temperature, but very slowly, the temperature of the body being much more suitable.

On *agar* or *glycerine-agar* at 37° C., growth is generally visible on the third or fourth day in the form of little transparent drops which gradually enlarge and form rounded projections of a reddish-yellow tint and somewhat transparent appearance, like drops of amber. The growths tend to remain separate, and even when they become confluent, the nodular character is maintained. They have a tough consistence, being with difficulty broken up, and adhere firmly to the surface of the agar. Older growths often show on the surface a sort of corrugated aspect, and may sometimes present the appearance of having been dusted with a brownish-yellow powder (Fig. 68). The organism grows well in the anærobic condition on agar, and for this purpose unopened eggs also, either in the fresh or boiled condition, have been used, inoculation being effected by drilling in the shell a small hole which is afterwards closed. The growth on *potatoes* is somewhat similar to that on agar.

FIG. 69.—Actinomyces, from a culture on glycerine-agar; showing the branching of the filaments.
Stained with fuchsin. × 1000.

On *gelatine* the same tendency to grow in little spherical masses is seen, and the medium becomes very slowly liquefied. When this occurs the liquefied portion has a brownish and somewhat syrupy consistence, and the growths may be seen at the bottom, as little balls, from the surface of which filaments radiate.

In the cultures at an early stage, numerous bacillary forms may be present, but later the growth is chiefly composed of filaments which show distinct branching (Fig. 69). Older filaments may become broken up into "cocci." True clubs are not formed in cultures, though slight bulbous thickenings may be seen at the end of some of the filaments.

Experimental Inoculation.—Some observers (*e.g.*, Boström) have obtained negative results by inoculation on animals, but Israel and Wolff succeeded in the case of guinea-pigs and rabbits. Intraperitoneal injection of the parasite in the bacillary or filamentous form was followed in a month by the production of nodules in the peritoneum from the size of a pea to that of a plum. The nodules were composed of granulation tissue, vascular on the surface, and containing fatty pus in which colonies of typical structure lay. These colonies showed clubs, though clubs were not present in the culture injected. The disease can also be reproduced by direct inoculation from an animal affected.

Methods of Examination and Diagnosis.—As actinomycosis cannot be diagnosed with certainty apart from the discovery of the parasite, a careful examination of the pus in obscure cases of suppuration should always be undertaken. As already stated, the colonies can be recognised with the naked eye, especially when some of the pus is spread out on a piece of glass. If one of these is washed in salt solution and examined unstained, the clubs, if present, are at once seen on microscopic examination. Or the colony may be stained with a simple reagent such as picrocarmine, and mounted in glycerine or Farrants' solution. To study the filaments, a colony should be broken down on a cover-glass, dried, and stained with a simple solution of any of the basic aniline dyes, such as gentian-violet, though better results are obtained by carbol-thionin-blue, or by carbol-fuchsin diluted with five parts of water. If the specimen be over-stained, it may be decolorised by weak acetic acid. Cover-glass preparations

of this kind and also of cultures, are readily stained by these methods, but in the case of sections of the tissues, Gram's method, or a modification of it, should be used to show the filaments, etc., a watery solution of rubin being afterwards used to stain the clubs. By this method, very striking preparations may be obtained.

To obtain cultures, tubes of glycerine-agar should be inoculated with portions of the colonies and incubated at 37° C., preferably both in the aërobic and anærobic condition. Owing to the slow growth of the actinomyces, however, the obtaining of pure cultures is difficult, unless the pus is free from contamination with other organisms.

Madura Disease.

Madura disease or mycetoma in many respects closely resembles actinomycosis, and is produced by a somewhat similar parasite, though it is still doubtful whether the organisms in the two conditions are of one and the same species. This disease is comparatively common in India and in various other parts of the tropics. It most frequently affects the foot; hence the disease is often spoken of as "Madura foot." The hand rarely is affected. In the parts affected there is a slow growth of granulation tissue which has an irregularly nodular character, and in the centre of the nodules there occurs purulent softening which is often followed by the formation of fistulous openings and ulcers. There occur great enlargement and distortion of the part and frequently caries and necrosis of the bones. Within the softened cavities and also in the spaces between the fibrous tissue, small rounded bodies or granules, bearing a certain resemblance to the actinomyces, are present. These may have a yellowish or pinkish colour, compared from their appearance to fish roe, or they may be black like grains of gunpowder, and may by their conglomeration form nodules of considerable size. Hence a yellow or pale, and a black variety of the disease have been distinguished.

In both varieties the granules mentioned reach a rather larger size than in actinomycosis.

When the roe-like granules are examined microscopically, they are found, like the actinomyces, to show in their interior an abundant mass of branching filaments with mycelial arrangement. There are also present at the periphery, structures which have a resemblance to the clubs in actinomyces. These structures often have an elongated wedge shape, forming an outer zone to the colony, and in some cases the filaments can be found to be connected with them. In the black variety, in many cases, the pigment is so abundant that all internal structure is obscured. In some cases, however, filaments may be found as in the yellow variety. In this variety the parasite would appear to be in a more or less degenerated condition, and the tissue round about the black masses is usually fibrous in character, their presence not being associated with much softening.

Regarding the exact relations of this organism there is still doubt. Kanthack considered that it had all the important characters of actinomyces and belonged to the same family, though without cultures he could not state definitely that the two species were identical. He also considered that the parasite was of the same nature in the pale and black varieties, and that probably the latter was a degenerated form of the former. Boyce and Surveyor, on the other hand, described the parasite as being composed of long non-branching septate filaments, and regarded it as belonging to the hyphomycetes or moulds. Vincent, however, has obtained cultures from a case of the disease occurring in Tunis, and the organism obtained, though resembling the actinomyces in many respects, is a distinct species. Vincent gives to it the name *streptothrix Maduræ*. The chief points of difference are the following: the streptothrix Maduræ does not liquefy gelatine; its cultures on the agar media have a reddish colour; it flourishes readily on certain vegetable infusions on which the actinomyces does not grow. Unlike the actinomyces again, it does not grow under anærobic conditions, and so far its inoculation on

animals has not been followed by any pathogenic effects. The results of Vincent would, therefore, show that the two organisms belong to the same genus, but are distinct species. It would, however, still require to be shown that the disease in the case studied by him was identical with that common in India, and also that in these conditions the parasite is always the same. It may also be mentioned that Madura disease differs from actinomyces, not only in its geographical distribution, but also in its clinical characters. Its course, for example, is of an extremely chronic nature, and though the local disease is incurable except by operation, the parasite never produces secondary lesions in internal organs. Vincent also found that iodide of potassium, which has a high value as a therapeutic agent in many cases of actinomycosis, had no effect in the case studied by him.

CHAPTER XIII.

ANTHRAX.[1]

OTHER NAMES.—SPLENIC FEVER, MALIGNANT PUSTULE, WOOLSORTER'S DISEASE. GERMAN, MILZBRAND; FRENCH, CHARBON.[2]

Introductory.—Anthrax is a disease occurring epidemically among the herbivora, especially sheep and oxen, in which animals it has the characters of a rapidly fatal form of septicæmia with splenic enlargement, attended by an extensive multiplication of characteristic bacilli throughout the blood. The disease does not occur as a natural affection in man, but may be communicated to him directly or indirectly from animals, and it may then appear in certainly two and possibly three forms. In the first there is infection through the skin. Here there is a local lesion, the "malignant pustule," which may lead to widespread œdema and lymphatic affection attended with fever, dyspnœa, hæmorrhagic enteritis, and often with a fatal result. On the other hand, the affection may remain local and recovery may take place. In the second form infection takes place through the respiratory tract. The symptoms start with

[1] In even recent works on surgery the term "anthrax" may be found applied to any form of carbuncle. Before its true pathology was known the local variety of the disease which occurs in man and which is now called "malignant pustule" was known as "malignant carbuncle."

[2] This must be distinguished from "charbon symptomatique," which is quite a different disease.

malaise, bronchial irritation, a sense of oppression across the chest, etc., and a rapidly fatal termination, with very aggravated symptoms centred in the thorax, usually follows. Thirdly, an infection may probably take place through the intestinal tract, which is now the first part to give rise to symptoms. In all these forms of the affection in the human subject, the bacilli are in their distribution much more restricted to the local lesions than is the case in the ox, their growth and spread being attended by inflammatory œdema and often by hæmorrhages.

Historical Summary.—Historical researches leave little doubt that from the earliest times anthrax has occurred among cattle. For a long time its pathology was not understood, and it went by many names. During the early part of the present century much attention was paid to it, and, with a view to finding out its nature and means of spread, various conditions attaching to its occurrence, such as those of soil and weather, were exhaustively studied. Pollender in 1849 pointed out that the blood of anthrax animals contained numerous rod-shaped bodies which he conjectured had some causal connection with the disease. In 1863 Davaine announced that they were bacteria, and originated for them the name *bacillus anthracis*. He stated that unless blood used in inoculation experiments on animals contained them, death did not ensue. Though this conclusion was disputed, still by the work of Davaine and others the causal relationship of the bacilli to the disease had been nearly established when the work of Koch appeared in 1876. This constituted that observer's first contribution to bacteriology, and did much to clear up the whole subject. Koch confirmed Davaine's view that the bodies were bacteria. He observed in the blood of anthrax animals the appearance of division, and from this deduced that multiplication took place in the tissues. He observed them under the microscope dividing outside the body, and noticed spore formation taking place. He also isolated the bacilli in pure culture outside the body, and by inoculating animals with them, produced the disease artificially.

In his earlier experiments he failed to produce death by feeding susceptible animals on either bacilli or spores, and as the intestinal tract was, in his view, the natural path of infection, he considered as incomplete the proof of this method of the rise of anthrax spontaneously in herds of animals. Koch's observations were, shortly afterwards, confirmed in the main by Pasteur, though controversy arose between them on certain minor points. Moreover, further research showed that the disease could be produced in animals by feeding them with spores, and thus the way in which the disease might spread naturally was explained.

The chief critic of Koch's work was Buchner, who stated that in the course of generations the B. anthracis became transformed into the bacillus subtilis, and also that the B. subtilis could by suitable precautions be transformed into the B. anthracis. These observations are now known to be quite erroneous, and possess no more than a historic interest.

Anthrax as a disease in man is of comparative rarity. Not only, however, is the bacillus anthracis easy of growth and recognition, but in its growth it illustrates many of the general morphological characters of the whole group of bacilli, and is therefore of the greatest use to the student. Further, its behaviour when inoculated in animals illustrates many of the points raised in connection with such difficult questions as the general pathogenic effects of bacteria, immunity, etc. Hence an enormous amount of work has been done in investigating it in all its aspects.

The Bacillus Anthracis.—If a drop of blood is taken immediately after death from an auricular vein of a cow, for example, which has died from anthrax, and examined microscopically, it will be found to contain a great number of large non-motile bacilli. On making a cover-glass preparation from the same source, and staining with watery methylene-blue, the characters of the bacilli can be better made out. They are about 1.2 μ thick or a little thicker, and 6 to 8 μ long, though both shorter and longer forms also occur. The ends are sharply cut across, or may be

slightly dimpled so as to resemble somewhat the proximal end of a phalanx. Their protoplasm is very finely granular, and sometimes appears surrounded by a thin unstained capsule. When several bacilli lie end to end in a thread, the capsule seems common to the whole thread (Fig. 74). They stain well with all the basic aniline dyes and are not decolorised by Gram's method.

Plate Cultures.—From a source such as that indicated, it is easy to isolate the bacilli by making gelatine or agar plates. If, after twelve hours' incubation at 37° C. the latter be examined under a low objective, colonies will be observed. They are to be recognised by beautiful wavy wreaths like locks of hair, radiating from the centre and apparently terminating in a point which, however, on examination with a higher power is observed to be a filament which turns upon itself (Fig. 70). The whole colony is, in fact, probably one long thread. Such colonies are very suitable for making impression preparations (*vide* p. 109) which preserve permanently the appearances described. On examining such with a high power, the wreaths are seen to be made up of bundles of long filaments lying parallel with one another, each filament consisting of a chain of bacilli lying end to end, and similar to those observed in the blood (Fig. 71).

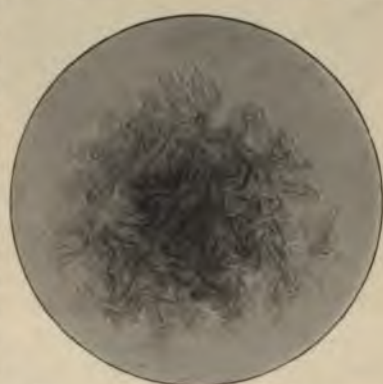

FIG. 70.—Surface colony of the anthrax bacillus on an agar plate, showing the characteristic appearances. × 30.

On gelatine plates, after from twenty-four to thirty-six hours at 20° C., the same appearances manifest themselves, and later they are accompanied by liquefaction of the

gelatine. In gelatine plates, however, instead of the characteristically wreathed appearance at the margin, the colonies

FIG. 71. — Anthrax bacilli, arranged in chains, from a twenty-four hours' culture on agar at 37° C.
Stained with fuchsin. × 1000.

FIG. 72. — Stab culture of the anthrax bacillus in peptone-gelatine; seven days' growth. It shows the "spiking" and also, at the surface, commencing liquefaction. Natural size.

sometimes give off radiating spikelets irregularly nodulated, which produce a star-like form. These spikelets are composed of spirally twisted threads. To such an appearance the term "fir-tree growth" is sometimes applied.

From such plates the bacilli can be easily isolated, and the appearances of pure cultures on various media studied.

Appearances of Cultures.—In *bouillon*, after twenty-four hours' incubation at 37° C. there is usually the appearance of irregularly spiral threads suspended in the liquid. These, on being examined, are seen to be made up of bundles of parallel chains of bacilli. Later, growth is more abundant, and forms a flocculent mass at the bottom of the fluid.

In *gelatine* stab cultures, the characteristic appearance can be best observed when a low proportion, say 7½ per cent, of gelatine is present, and when the tube is directly inoculated from anthrax blood. In about two days there radiate out into the medium from the needle track numberless very fine spikelets which enable the cultures to be easily recognised. These spikelets are longest at the upper part of the needle track (Fig. 72). Not much spread takes place on the surface of the gelatine, but here liquefaction commences, and gradually spreads down the stab and out into the medium, till the whole of the gelatine may be liquefied. Gelatine slope cultures exhibit a thick felted growth, the edges of which show the wreathed appearance seen in plate cultures. Liquefaction here soon ploughs a trough in the surface of the medium. Sometimes "spiking" does not take place in gelatine stab cultures, only little round particles of growth occurring down the needle track, followed by liquefaction. Agar sloped cultures have the appearance of similar cultures in gelatine, though, of course, no liquefaction takes place.

Blood serum sloped cultures present the same appearances as those on agar. The margin of the surface growth on any of the solid media shows the characteristic wreathing seen in plate colonies.

On *potatoes* there occurs a thick felted white mass of bacilli showing no special characters.

The anthrax bacillus will thus grow readily on any of the ordinary media. It can usually be sufficiently recognised by its microscopic appearance, by its growth on agar or gelatine plates, and by its growth in gelatine stab cultures. The growth on plates is specially characteristic, and is simulated by no other pathogenic organism. Among the non-pathogenic bacteria the only organism which has similar colonies is the bacillus figurans, and the resemblance is only a distant one.

The Biology of the B. anthracis.—Koch found that the bacillus anthracis grows best at a temperature of 35° C. Growth, *i.e.*, multiplication, does not take place below 12° C.

or above 45° C. In the spore-free condition the bacilli have comparatively low powers of resistance. They do not stand long exposure to 60° C., and if kept at ordinary temperature in the dry condition they are usually found to be dead after a few days. The action of the gastric juice is rapidly fatal to them, and they are accordingly destroyed in the stomachs of healthy animals. They are also soon killed in the process of putrefaction. They can, however, be cooled below the freezing-point without dying. The bacillus can grow without oxygen, but some of its vital functions are best carried on in the presence of this gas. Thus in anthrax cultures the liquefaction of gelatine always commences at the surface and spreads downwards. Growth is more rapid in the presence of oxygen, and spore formation does not occur in its absence. The organism may probably be classed as a facultative anærobe.

Sporulation.—Under certain circumstances sporulation occurs in anthrax bacilli. The morphological appearances are of the ordinary kind. A little highly-refractile speck appears in the protoplasm about the centre of the bacillus; this gradually increases in size until it forms an oval body about the same thickness as the bacillus lying in the bacillary protoplasm (Fig. 73). The latter gradually loses its staining capacities and finally disappears, the part that is not absorbed within the spore being probably dissolved with the membrane in the surrounding

FIG. 73. — Anthrax bacilli containing spores (the darkly coloured bodies); from a three days' culture on agar at 37° C.
Stained with carbol-fuchsin and methylene-blue. × 1000.

medium. The spore thus lies free as an oval highly-refractile body which does not stain by ordinary methods, but which can be easily stained by the special methods described for such a purpose (p. 103). When the spore is again about to assume the bacillary form the capsule is apparently absorbed, and the protoplasm within grows out, taking on the ordinary rod-shaped form.

According to most observers sporulation never occurs within the body of an animal suffering from anthrax. Koch attributes this, probably rightly, to the absence of free oxygen. The latter gas he found necessary to the occurrence of spores in ordinary media growing outside the body. Many, however, are inclined to assign as the cause of sporulation the absence of the optimum pabulum, which in the case of anthrax is afforded by the animal tissues. Besides these conditions there is another factor necessary to sporulation, viz. a suitable temperature. The optimum temperature for spore production is 37° C. Koch found that spore-formation did not occur below 18° C. Above 42° C. not only does sporulation cease, but Pasteur found that if bacilli were kept at this temperature for eight days, on being again grown at a lower temperature, they did not regain the capacity. In order to make them again capable of sporing it is necessary to adopt special measures, such as passage through the bodies of a series of susceptible animals.

Anthrax spores are extremely resistant organisms. In a dry condition they will remain viable for a year or more. Koch found they resisted boiling for five minutes; and dry heat at 140° C. must be applied for several hours to kill them with certainty. Unlike the bacilli, they can resist the action of the gastric juice for a long period of time.

Anthrax in Animals.—Anthrax occurs from time to time epidemically in sheep, cattle, and, more rarely, in horses and deer. Geographically these epidemics are found in various parts of the world, although naturally they are most far-reaching where legal precautions to prevent the spread of infection are non-existent. All the countries of Europe are from time to time visited by the disease, though

in some it is much more common than in others. In Britain the death-rate is small, but in France the annual mortality among sheep was probably 10 per cent of the total number in the country, and among cattle 5 per cent. These figures, however, have been largely modified by the system of preventive treatment which will be presently described. In sheep and cattle the disease is specially virulent. An animal may suddenly drop down, with symptoms of collapse, quickening of pulse and respiration, and dyspnœa, and death may occur in a few minutes. In less acute cases the animal is apparently out of sorts, and does not feed; its pulse and respiration are quickened; rigors occur, succeeded by high temperature; there is a sanguineous discharge from the bowels, and bloody mucus may be observed about the mouth and nose. There may be convulsive movements, there is progressive weakness, with cyanosis, death occurring in from twelve to forty-eight hours. In the more prolonged cases widespread œdema and extensive enlargement of lymphatic glands are marked features; and in the glands, especially about the neck, actual necrosis with ulceration may occur, constituting the so-called anthrax carbuncles. Such subacute conditions are especially found among horses, which are by nature not so susceptible to the disease as cattle and sheep.

On *post-mortem* examination of an ox dead of anthrax, the most noticeable feature—one which has given the name "splenic fever" to the disease—is the enlargement of the spleen, which may be two to three times its natural size. It is of dark-red colour, and on section the pulp is very soft and friable, sometimes almost diffluent. A cover-glass preparation may be made from the spleen and stained with watery methylene-blue. On examination it will be found to contain enormous numbers of bacilli mixed with red corpuscles and leucocytes, chiefly lymphocytes and the large uninucleated variety (Fig. 74). Pieces of the organ may be hardened in absolute alcohol, and sections cut in paraffin. These are best stained by Gram's method. Microscopic examination of such shows that the structure of the

pulp is considerably disintegrated, whilst the bacilli swarm throughout the organ, lying irregularly amongst the cellular elements. The liver is enlarged and congested, and may be in a state of acute cloudy swelling. The bacilli are present in the capillaries throughout the organ, but are not so numerous as in the spleen. The kidney is in a similar

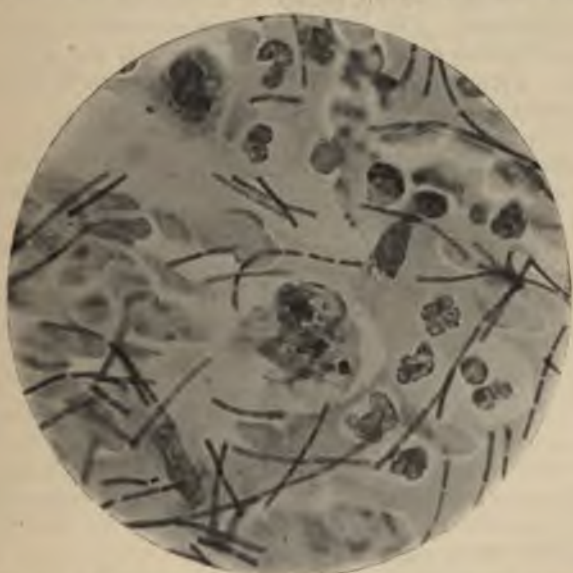

FIG. 74.—Scraping from spleen of guinea-pig dead of anthrax, showing the bacilli mixed with leucocytes, etc. (Same appearance as in the ox.) "Corrosive-film" stained with carbol-thionin-blue. × 1000.

condition, and here the bacilli are chiefly found in the capillaries of the glomeruli, which often appear as if injected with them. The lungs are congested and may show catarrh, whilst bacilli are present in large numbers throughout the capillaries, and may also be found in the air-cells, probably as the result of rupture of the capillaries. The blood throughout the body is usually fluid and of dark colour.

The lymphatic system generally is much affected. The glands, especially the mediastinal, mesenteric, and cervical glands, are enlarged and surrounded by œdematous tissue, the lymphatic vessels are swollen, and both glands and vessels may contain numberless bacilli. The heart may be in a state of acute cloudy swelling, and the blood in its cavities contains bacilli, though in smaller numbers than in the capillaries. The intestines are enormously congested, the epithelium catarrhal and the lumen filled with a bloody fluid. From all the organs the bacilli can be easily isolated by stroke cultures on agar.

It is important to note the existence of great differences in susceptibility to anthrax in different species of animals. Thus the ox, sheep (except those of Algeria), guinea-pig, and mouse are all very susceptible, the rabbit slightly less so. The last three are of course most used for experimental inoculation. We have no data to determine whether the disease occurs among these in the wild state. Less susceptible than this group are the horse, deer, goat, in which the disease occurs from time to time in nature, as it also does, though rarely, in the pig. The human subject may be placed next in order of susceptibility, man thus occupying a medium position between the highly susceptible and the relatively immune animals. The white rat is highly immune to the disease, while the brown rat is susceptible. Adult carnivora are also very immune, and the birds and amphibia are in the same position.

With these differences in susceptibility there are also great variations in the pathological effects produced in the natural or artificial disease. This is especially the case when we consider the distribution of the bacilli in the body of an animal dead of the affection. Instead of the widespread occurrence described above, they may be confined to the point where they first gained access to the body and the lymphatic system in relation to it, or may be only very rarely scattered in organs such as the spleen (which is often not enlarged), the lungs, or kidneys. Nevertheless the cellular structure of the organs even in such a case may

show changes, a fact which is important when we consider the essential pathology of the disease.

Experimental Inoculation.—Of the animals commonly used in laboratory work, white mice and guinea-pigs are the most susceptible to anthrax, and are generally used for test inoculations. If a small quantity of anthrax bacilli

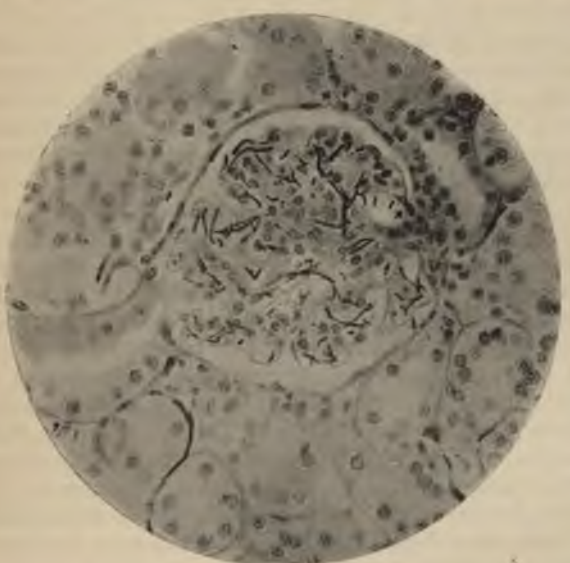

FIG. 75.—Portion of kidney of a guinea-pig dead of anthrax, showing the bacilli in the capillaries, especially of the glomerulus.
Paraffin section; stained by Gram's method and Bismarck-brown. × 300.

be injected into the subcutaneous tissue of a guinea-pig, a fatal result follows, usually within two days. *Post mortem* around the site of inoculation the tissues are swollen and gelatinous in appearance, owing to intense inflammatory œdema, and on microscopic examination show numerous bacilli. The internal organs show congestion and cloudy

swelling, with sometimes small hæmorrhages, and their capillaries contain enormous numbers of bacilli, as has already been described in the case of the ox (Fig. 75); the spleen also shows a corresponding condition. Highly susceptible animals may also be infected by being made to inhale the bacilli or their spores, and also by being fed with spores, a general infection rapidly occurring by both methods.

Anthrax in the Human Subject.—As we have noted, man occupies a middle position in the scale of susceptibility to anthrax. It is always communicated to him from animals, and usually is seen among those whose trade leads them to handle the carcases or skins of animals which have died of the disease. It occurs in two principal forms, the main difference between which is the site of entrance of the organism into the body. In one, the path of entrance is through cuts or abrasions in the skin, or through the hair follicles. A local condition called a "malignant pustule" develops, which may lead to a general infection. This variety occurs chiefly among butchers and those who work among hides (foreign ones especially). In Britain the workers of the latter class chiefly liable are the hide-porters and hide-workers in south-eastern London. In the other variety of the disease, the site of infection is the trachea and bronchi, and here a fatal result almost always follows. The cause is the inhalation of dust or threads from wool which has been taken from sheep dead of the disease, and which has been contaminated with blood or secretions containing the bacilli, these having afterwards formed spores. From the fact that this variety occurs in the centres of the wool stapling trade (in England, chiefly in Yorkshire), it is called "woolsorter's disease."

(1) *Malignant Pustule.*—This usually occurs on the exposed surfaces—the face, hands, forearms, and back, the last being a common site among hide-porters. One to three days after inoculation a small red painful pimple appears, soon becoming a vesicle, which may contain clear or blood-stained fluid, and is rapidly surrounded by an area of

intense congestion. Central necrosis occurs and leads to the malignant pustule proper, which in its typical form appears as a black eschar often surrounded by a ring of vesicles, which in turn are surrounded by a congested area. From this pustule as a centre, subcutaneous œdema spreads, especially in the direction of the lymphatics; the neighbouring glands are enlarged. There is fever and a general feeling of illness. On microscopic section of the typical pustule, the central eschar is noticed to be composed of necrosed tissue and altered blood; the vesicles are formed by the raising of the stratum corneum from the rete Malpighi. Beneath them and in their neighbourhood the cells of the latter are swollen and œdematous, the papillæ being flattened out and infiltrated with inflammatory exudation. The cells become necrosed, and go to form the eschar. The subcutaneous tissue is also œdematous, and often infiltrated with leucocytes. The bacilli exist in the peripheræ of the eschar and in the neighbouring lymphatics, and, to a certain extent, in the vesicles. It is very important to note that widespread œdema of a limb, enlargement of neighbouring glands, and fever may occur while the bacilli are still confined to the immediate neighbourhood of the pustule. Sometimes the pathological process goes no further, the eschar becomes a scab, the inflammation subsides, and recovery takes place. In the majority of cases, however, if the pustule be not excised, the œdema spreads, invasion of the blood stream may occur, and the patient dies with, in a modified degree, the pathological changes detailed with regard to the acute disease in cattle. In man the spleen is usually not much enlarged, and the organs generally may contain few bacilli. It may here be said that early excision of an anthrax pustule, especially when the latter is situated in the extremities, is followed, in a large proportion of cases, by recovery.

(2) *Woolsorter's Disease.*—The pathology of this affection was worked out in this country especially by Greenfield. The local lesion is usually situated in the lower part of the trachea or in the large bronchi, and is in the form of swollen

patches in the mucous membrane often with hæmorrhage into them. The tissues are œdematous, and the cellular elements are separated, but there is usually little or no necrosis. There is enormous enlargement of the mediastinal and bronchial glands, and hæmorrhagic infiltration of the cellular tissue in the region. There is pleural and pericardial effusion, and hæmorrhagic spots occur beneath the pleuræ. The lungs show collapse and œdema. There may be cutaneous œdema over the chest and neck, with enlargement of glands, and the patient rapidly dies with symptoms of pulmonary embarrassment, and with a varying degree of pyrexia. It is to be noted that in such cases though numerous bacilli are present in the bronchial lesions, in the lymphatic glands, and affected tissues in the thorax, comparatively few may be present in the various organs, such as kidneys, spleen, etc., and sometimes it may be impossible to find any.

(3) It is probable that infection occasionally takes place through the intestine; but this condition is rare. In such cases there is a local lesion in the intestinal mucous membrane, of similar nature to that in the bronchial form, and a corresponding affection of the mesenteric glands.

The Pathology of Anthrax.—Anthrax is one of the diseases regarding the bacterial origin of which there is no doubt. The anthrax bacillus is always found in animals naturally dead of the disease, and can be isolated in pure culture. Further, when re-injected into other animals of the same species it reproduces the pathological picture seen in the animal from which it was derived. The proof being thus absolute, we have only to consider how the B. anthracis produces its pathological effects, and how the disease is spread in nature. We have seen that the chief features of the disease are, on the one hand, the extensive multiplication of the bacilli in the tissues, and, on the other hand, the changes produced in the tissues both in the neighbourhood of the bacilli and also in the various organs apart from their presence. We have to consider how these various tissue changes, as well as the various toxic phenomena, may be brought about

by the agency of the bacilli. Various theories were formerly held on this subject. One of the earliest was the mechanical, according to which it was supposed that the serious results were produced by extensive blocking of the capillaries in the various organs by the bacilli. According to another, it was supposed that the bacilli used up the oxygen of the blood, thus leading to starvation of the tissues. Though such modes of action may occur to a small extent, we now know that in anthrax, as in other diseases, the important local and general effects are produced by specific poisons formed by the bacilli. We have therefore to consider the nature of these toxic bodies.

The Toxines of the Bacillus Anthracis.—During the years 1889-90 several papers were published dealing with the toxines of the bacillus anthracis. Hankin, investigating the means of conferring immunity against the disease, isolated from cultures in a bouillon made from Liebig's meat juice an albumose which he considered to be the toxine. His reason for thinking so was that, while the injection of very small doses of this substance (one five millionth to one ten millionth of the weight of an animal) lengthened the incubation period of the disease, and might even ward off a fatal attack, the injection of larger doses hastened the death of the animal. Very full researches on the subject were carried out by Sidney Martin. This observer used alkali-albumin as the medium on which to grow the bacillus, that medium approaching most closely to its environment when growing in the animal body. From cultures in this medium there were isolated proto-albumose, deutero-albumose, and traces of peptone. The albumoses differed from those which occur in ordinary digestion, in being strongly alkaline in their reaction. This alkalinity, Martin held, was due to traces of an alkaloidal body of which the albumoses were the precursors, and which occurred when the process of digestion of the alkali-albumin by the bacillus was allowed to go on further. By the albumoses and the alkaloid, pathogenic effects were produced in animals, closely similar to those produced by the bacilli themselves. Martin adduces evidence to show

that, of the symptoms of the disease, the fever was mostly due to the albumoses, while the œdema and congestion were mostly due to the alkaloid which acted as a local irritant. He showed that prolonged boiling destroyed the activity of the albumose, but not that of the alkaloid. Further, from the body fluids of animals dead of anthrax he isolated poisonous bodies identical with those produced by the bacilli growing in this artificial medium. Hankin, in a later research with Wesbrook, arrived at the conclusion that the bacillus anthracis produces a ferment which, diffusing out into the culture fluid, elaborates albumoses from the proteids present in it. The bacilli also produce albumoses directly without the intervention of a ferment. The albumoses produced in the latter way, when injected in small doses, produce in susceptible animals immunity against subsequent inoculation with virulent bacilli, but are only toxic to animals not very susceptible to the disease. Marmier, after cultivating the B. anthracis in peptone solution containing certain salts, removed all the albumoses from the resultant liquid, and from them, either by dialysis or extraction with glycerine, isolated a body which gave no reactions of albuminoid matter, peptone, propeptone, or alkaloid. This he considers the toxine. It killed animals susceptible to anthrax by a sort of cachexia, and in suitably small doses could be used to immunise them against subsequent inoculation with virulent bacilli. It was chiefly retained within the bacilli when these were growing in the most favourable conditions. Unlike the toxines of tetanus and diphtheria, and unlike ferments, it was not destroyed by heating to 110° C.

From this account of the researches into the toxines of the B. anthracis, it will be seen that our knowledge is far from complete. It is difficult to say what interpretation is to be put on the results of Hankin and Wesbrook. The researches of Marmier rather indicate that, as is the case with the toxines of other bacilli, the toxine of anthrax may belong to a group of bodies of whose chemical nature we are in complete ignorance. Be this as it may, the results detailed

open up a way for our arriving at an idea of the true pathology of the disease. The bacilli in all parts of the body, whether directly or intermediately by ferments, produce bodies toxic to tissue cells. Further, bacilli confined locally produce by this means effects on distant tissues. This explains how in certain cases, while the bacilli are still locally confined, there may occur œdema spreading from the pustule, and pyrexia.

The Spread of the Disease in Nature.—If we take the case of an animal suffering from anthrax, we have to ask how it communicates the disease to others. We have seen that the B. anthracis rarely, if ever, forms spores in the body, and if the bacilli could be confined to the blood and tissues of the carcase, it is certain that anthrax in an epidemic form would rarely occur. For it has been shown by many observers that in the course of the putrefaction of such a carcase the anthrax bacilli rapidly die out, and that after ten days or a fortnight very few remain. But it must be remembered that while still alive, an animal is shedding into the air by the bloody excretions from the mouth, nose, and bowel, myriads of bacilli which may rapidly spore, and thus arrive at a very resistant stage. These lie on the surface of the ground and are washed off by surface water. At certain seasons of the year the temperature is, however, sufficiently high to permit of their germination, and also of their multiplication, as they can undoubtedly grow on the organic matter which occurs in nature. They can again form spores. It is in the condition of spores that they are dangerous to susceptible animals. In the bacillary stage, if swallowed, they will be killed by the acid gastric contents; but as spores they can pass uninjured through the stomach, and, gaining an entrance into the intestine, infect its wall, and ultimately reach, and multiply in, the blood. It was thought by some, including Pasteur, that infection took place by bacilli infecting excoriations about the mouth and fauces; and the occasional occurrence of great lymphatic enlargement in the cervical region was adduced in support of this view. It was also supported by the want of success

which attended the earlier efforts to cause the disease artificially by feeding animals on bacilli and spores. When, however, it was proved that the latter could cause the disease on gaining entrance into the intestinal canal, this theory was no longer necessary, and it is now known that in the great majority of cases of the disease in sheep and oxen, infection takes place from the intestine. It was thought by Pasteur that worms were active agents in the natural spread of the disease by bringing to the surface anthrax spores. Koch made direct experiments on this point, and could get no evidence that this was the case. He thinks it much more probable that the recrudescence of epidemics in fields where anthrax carcases have been buried, is due to persistence of spores on the surface which has been infected by the cattle when alive.

The Disposal of the Carcases of Animals dead of Anthrax.—It is extremely important that anthrax carcases should be disposed of in such a way as to prevent their becoming future sources of infection. If anthrax be suspected as the cause of death no *post mortem* should be made, but only a small quantity of blood be removed from an auricular vein for bacteriological investigation. If such a carcase be now buried in a deep pit surrounded by quicklime, little danger of infection will be run. The bacilli being confined within the body will not spore, and will die during the process of putrefaction. The danger of sporulation taking place is, of course, much greater when an animal has died of an unknown disease which on *post-mortem* examination has proved to be anthrax, but similar measures for burial must be here adopted. In some countries anthrax carcases are burned, and this, if practicable, is of course the best means of treating them. The chief source of danger to cattle subsequently, however, proceeds from the infection of fields, yards, and byres with the offal, and the discharge from the mouths of anthrax animals. All material that can be recognised as such should be burned along with the straw in which the animals have lain. The stalls or buildings in which the anthrax cases have been must be limewashed. Needless to say, the greatest care must be taken in the case of men who handle the animal or its carcase that they have no wounds on their persons, and that they thoroughly disinfect themselves by washing the hands, etc., in 1 to 1000 solution of corrosive sublimate, and that all clothes soiled with blood, etc., from anthrax animals be thoroughly boiled or steamed for half an hour before being washed.

The Immunising of Animals against Anthrax.—Having ascertained that there was ground for believing that in cattle one attack of anthrax protected against a second, Pasteur in the years 1880-82) elaborated a method by which a mild form of the disease could be given to animals, which rendered harmless a subsequent inoculation with virulent bacilli. He found that the continued growth of anthrax bacilli at 42° to 43° C. caused them to lose their capacity of producing spores, and also gradually to lose their virulence, so that after twenty-four days they could no longer kill either guinea-pigs, rabbits, or sheep. Such cultures constituted his *premier vaccin*, and protected against the subsequent inoculation with bacilli which had been grown for twelve days at the same temperature, and the attenuation of which had therefore not been carried so far. The latter constituted the *deuxième vaccin*. It was further found that sheep thus twice vaccinated now resisted inoculation with a culture which usually would be fatal. The method was to inoculate a sheep on the inner side of the thigh by the subcutaneous injection, by a hypodermic syringe, of about five drops of the *premier vaccin;* twelve days later to again inoculate with the *deuxième vaccin;* fourteen days later an ordinary virulent culture was injected without any ill result. This method was applicable also to cattle and horses, about double the dose of each vaccine being here necessary. Extended experiments in France generally confirmed earlier results, and the method was, before long, used to mitigate the disease, which in many departments was endemic and a very great scourge. Since that time the method has been regularly in use. It is difficult to arrive at a certain conclusion as to its merits. Undoubtedly a certain number of animals die of anthrax either after the first or second vaccination, or during the year following vaccination. At the end of a year the immunity is lost in about 40 per cent of the animals vaccinated; and thus to be permanently efficacious the process would have to be repeated every year. Further, the immunity is much higher in degree if, after the first and second vaccinations, an inoculation with virulent anthrax is performed.

Everything being taken into account, however, there is no doubt that the mortality from natural anthrax is much diminished by this system.

Statistics are available for the twelve years 1882-93. During that time 3,296,815 sheep were vaccinated, with a mortality, either after the first or second vaccination or during the subsequent twelve months, of .94 per cent, as contrasted with the ordinary mortality in all the flocks of the districts, of 10 per cent. During the same time 438,824 cattle were vaccinated, with a mortality of .34 per cent, as contrasted with a probable mortality of 5 per cent if they had been unprotected.

Other means of immunising animals against anthrax have been elaborated, but these have a more strictly scientific interest. In dealing with the toxines of anthrax we have already referred to the work of Hankin and Wesbrook on this point. We have also seen that Marmier succeeded in immunising animals by using a toxine isolated by him. Even, however, as a method of immunising animals for scientific observations Pasteur's method still obtains.

Serum Anticharbonneux.—The properties of the serum of animals vaccinated against anthrax have been investigated by Marchoux. The animals were immunised in the usual way. The serum of sheep and especially of rabbits was found to afford a certain degree of protection to susceptible animals against subsequent inoculation with virulent bacilli. It also exhibited a small degree of curative action. When it was injected immediately after inoculation with the bacilli a certain number of the animals survived, but in proportion as the symptoms of the disease (œdema, fever, etc.) were established, so was the curative effect diminished, even though large doses of the serum were employed. According to Marchoux, this serum stimulates the phagocytes successfully to attack the bacilli. Such a serum would probably fall to be classed as anti-microbic and not anti-toxic, but its properties require further investigation.

Methods of Examination.—These include (*a*) microscopic examination; (*b*) the making of cultures; and (*c*) test inoculations.

(*a*) *Microscopic Examination.*—In a case of suspected

malignant pustule, film preparations should be made from the fluid in the vesicles or from a scraping of the incised or excised pustule, and stained with a watery solution of methylene-blue and also by Gram's method. By this method practically conclusive evidence may be obtained; but sometimes the result is doubtful, as the bacilli may be few in number. In all cases confirmatory evidence should be obtained by culture. It should be noted that the greatest care ought to be taken in handling the part, as otherwise the diffusion of the bacilli into the surrounding tissues may be aided and the condition greatly aggravated. The examination of the blood in cases of anthrax in man usually gives negative results, with the exception of very severe cases, when a few bacilli may be found in the blood shortly before death, though even then they may be absent.

(*b*) *Cultivation.*—A small quantity of the material used for microscopic examination should be taken on a platinum needle, and successive strokes made on agar tubes, which are then incubated at 37° C. At the end of twenty-four hours anthrax colonies will appear, and can be readily recognised from their wavy margins, by means of a hand lens. They should also be examined microscopically by means of film preparations.

(*c*) *Test Inoculations.*—A little of the suspected material should be mixed with some sterile bouillon or water, and injected subcutaneously into a guinea-pig, or it may be introduced into the subcutaneous tissue by means of a seton. If anthrax bacilli are present, the animal usually dies within two days, with the changes in internal organs already described.

CHAPTER XIV.

TYPHOID FEVER.

OTHER NAMES. — ENTERIC FEVER: GASTRIC FEVER. GERMAN, TYPHUS ABDOMINALIS: ABDOMINALTYPHUS: UNTERLEIBSTYPHUS. FRENCH, LA FIÈVRE TYPHOÏDE.

Historical Summary. — During the early part of the bacteriological era many observers had described various micrococci and bacilli, and even higher forms, as occurring in the neighbourhood of the typhoid ulcers and in the tissues generally, but the first definite descriptions of what is now known as the bacillus typhosus appeared about 1880-81, when the papers of Eberth, Koch, and Klebs were published. On account of priority of publication and of the general confirmation of his observations by later observers, the credit of the discovery is generally assigned to Eberth, and the bacillus typhosus is often called Eberth's bacillus. This worker investigated in all forty cases of the disease, examining especially the mesenteric lymphatic glands and the spleen, and in twenty-two he found what he considered to be characteristic bacilli. These are now identified with the bacillus typhosus. They occurred in the intestinal ulcers, in the spleen, and lymphatic glands. Eberth came to the conclusion that they were not putrefactive organisms, and further that they had a specific relation to the disease, but he made no attempts to grow them outside the body. This important step was taken by

Gaffky (1884). This author confirmed Eberth's observations on the occurrence of the bacilli in the organs of typhoid cases, and succeeded in obtaining from the spleen pure cultures in gelatine. He further recognised very fully the morphological character of the bacilli both in cultures and when occurring in the body, though he described them as spore-bearing, an observation which, as we shall see, is now considered erroneous. He noted the growth on potatoes as characteristic, and this is still looked on as an important point. He held that the bacilli were not putrefactive, as he found they did not produce putrefactive effects on artificial media; but all his attempts to reproduce by their means the disease in different species of animals (including monkeys) were unsuccessful. This difficulty has not been fully overcome. The position, therefore, was that in the great majority of cases of typhoid fever, characteristic bacilli could be found and isolated in pure culture, but that these did not give rise to the disease in animals.

During the years succeeding the publication of the work of Eberth, Koch, and Gaffky, the results of these investigators were confirmed so far as they went, but little advance was made towards a clearer knowledge of the causation of the disease. The discovery in 1885 of another micro-organism closely resembling the typhoid bacillus and normally appearing in the human intestine, caused questionings as to the bacillus of Eberth having a causal relationship to typhoid fever. In the year named, Escherich, working on the first appearance of organisms in the bowel of the new-born infant, described a bacillus which he named the *bacillus coli communis* (often subsequently named the *bacterium coli commune* and also Escherich's bacillus). About the same time Emmerich described a bacillus which he found in the intestines of the victims of a cholera epidemic at Naples, and to which considerable attention was directed on account of the author setting it up as the causal agent in cholera in opposition to the vibrio of Koch. Resulting investigation

indicated that this bacillus (known as Emmerich's bacillus or the bacillus Neapolitanus) was identical with that described by Escherich. Weisser, who worked at the subject, pointed out that the B. coli was a normal inhabitant of the human intestine; and, further, comparing the growth characters of the bacillus coli communis with those of the typhoid bacillus, noted the similarities which exist between the two microbes.

From this time forward, the question of the morphological relationships of the two organisms has played an important part in the bacteriological investigation of the subject. There has been much controversy as to whether they are varieties of the same species, and also as to whether, in view of the fact that the B. coli is a normal inhabitant of the human intestine, the B. typhosus may not originate *de novo* from it in every case. The result is a growing conviction that, for an unknown time, at any rate, the two have been distinct species. Within late years the significance of the pathogenic effects which the B. typhosus produces in animals has been much discussed, and the production by it of toxic bodies has formed the subject of many investigations.

The Bacillus Typhosus — *Microscopic Appearances.* — Most observers will agree with Gaffky in attributing any failure to find typhoid bacilli in the organs of a typhoid patient to the difficulties of the search. Numerous sections of different parts of a spleen, for example, may be examined before a characteristic group is found. The best tissues for examination are a Peyer's patch where ulceration has not yet commenced or where it is just commencing, the spleen, the liver, or a mesenteric gland. The spleen and liver are better than the other tissues named, as in the latter the presence of the B. coli is more frequent. From scrapings of such solid organs dried films may be prepared and stained for a few minutes in the cold by any of the strong staining solutions, *e.g.*, with carbol-thionin-blue, or with Ziehl-Neelsen's carbol-fuchsin diluted with five parts of distilled water. As a rule, decolorising is not necessary.

For the proper observation of the arrangement of the bacilli in the tissues, paraffin sections should be prepared and stained in carbol-thionin-blue for a few minutes, or in Löffler's methylene-blue for one to two hours. The bacilli take up the stain somewhat slowly, and as they are also easily decolorised, the aniline oil method of dehydration

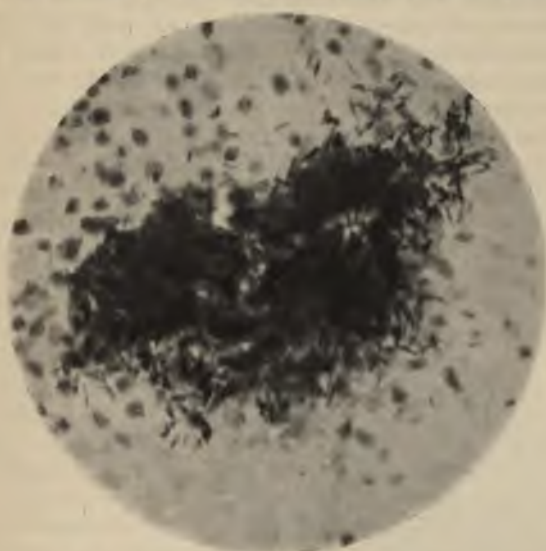

FIG. 76.—A specially large clump of typhoid bacilli in a spleen. The individual bacilli are only seen at the periphery of the mass. (In this spleen, enormous numbers of typhoid bacilli were shown by cultures to be present in a practically pure condition.)
Paraffin section; stained with carbol-thionin-blue. × 500.

may be used with advantage (*vide* page 96). In such preparations the characteristic appearance to be looked for is the occurrence of groups of bacilli lying between the cells of the tissue (Fig. 76). The individual bacilli are 2 μ to 4 μ long, with somewhat oval ends, and .5 μ in thickness. Sometimes filaments 8 μ to 10 μ long may be observed, though

they are less common than in cultures. It is evident that one of the short oval forms may frequently in a section be viewed endwise, in which case the appearance will be circular. This appearance accounts for some, at least, of the coccus-like forms which have been described. The bacilli are decolorised by Gram's method.

Isolation and Appearances of Cultures.—To grow the organism artificially it is best to isolate it from the spleen, as it exists there in greater numbers than in the other solid organs, and may be the sole organism present even some time after death. The spleen is removed whole, and a portion of its capsule is seared with a hot piece of metal in order that all superficial contaminating organisms may be destroyed. A small incision is made into the organ with a sterile knife, a little of the pulp removed by a platinum needle, and agar or gelatine plates are prepared, or successive strokes made on agar tubes. On the agar media the growths are visible after twenty-four hours' incubation at 37° C. On agar plates the superficial colonies appear as circular spots, dull white by reflected light, bluish-grey by transmitted light. Colonies in the substance of the agar are small, and appear as minute round points. When viewed under a low objective, the surface colonies are found to be very transparent (requiring a small diaphragm for their definition), finely granular in appearance, and with a very coarsely crenated and well-defined margin. The deep colonies are usually

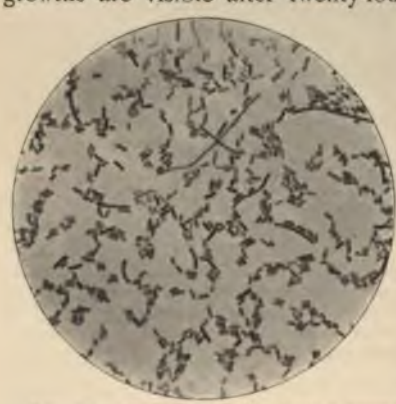

FIG. 77.—Typhoid bacilli; from a young culture on agar, showing some filamentous forms.
Stained with weak carbol-fuchsin. × 1000.

spherical, sometimes lenticular in shape, and are smooth or finely granular on the surface, and more opaque than the superficial colonies. On making cover-glass preparations, the bacilli are found to present the same microscopic appearances as are observed in preparations from solid organs, except that there is a proportionately greater number of the long forms which may almost be called filaments (Fig. 77). The same is true of films made from young gelatine colonies. Sometimes the diversity in the length of the bacilli is such as to throw doubts on the purity of the culture. Its purity of course can be readily tested by preparing plates from it in the usual way. As a general rule in a young (twenty-four to forty-eight hours old) colony, grown at a uniform temperature, the bacilli are plump, and the protoplasm stains uniformly. In old cultures or in cultures which have been exposed to change of temperature, the protoplasm stains only in parts; there may be an appearance of vacuolation either at the centre or at the ends of the bacilli, or a bacillus may resemble a string of irregular coccus-like bodies. It is these appearances which have led some to believe that the typhoid bacillus forms spores. Gaffky described the latter as highly refractile bodies occurring at the ends of the bacillus, and others have thought that the coccus-like bodies are spores. Cultures containing either have, however, been found to be not more highly resistant than those containing ordinary bacilli; further, the staining reactions of such bodies are not those of spores, so that now it is generally believed that spore-formation does not occur in the typhoid bacillus.

Motility.—In hanging-drop preparations the bacilli are found to be actively motile. The smaller forms have a darting or rolling motion, passing quickly across the field, whilst some show rapid rotatory motion. The filamentous forms have an undulating or serpentine motion, and move more slowly. Hanging-drop preparations ought to be made from agar or broth cultures not more than twenty-four hours old. In older cultures the movements are less active.

Flagella.—On being stained by the appropriate methods (*vide* p. 104) the bacilli are seen to possess many long wavy flagella which are attached all along the sides and to the ends (Fig. 78). They are more numerous, longer, and more wavy than those of the B. coli.

Characters of Cultures.—Stab cultures in *peptone-gelatine*

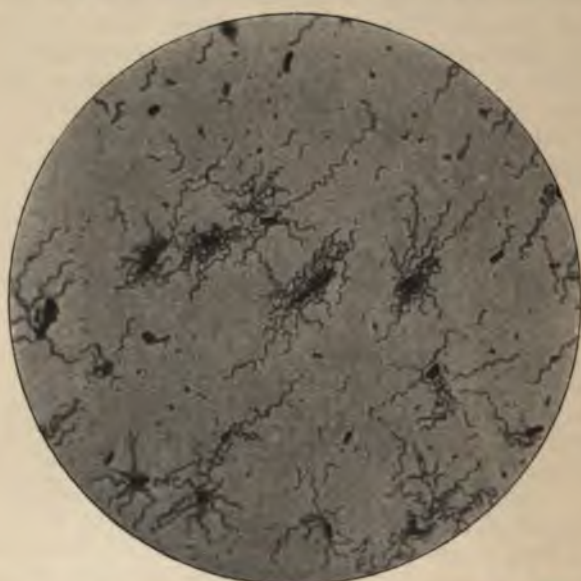

FIG. 78.—Typhoid bacilli, from a young culture on agar, showing flagella.
Stained by Van Ermengem's method. × 1000.

give a somewhat characteristic appearance. On the surface of the medium, growth spreads outwards from the puncture as a thin film or pellicle, with irregularly wavy margin (Fig. 79, A). It is semi-transparent, and of bluish-white colour. Ultimately this surface growth may reach the wall of the tube. Along the stab there is an opaque whitish

line of growth, of finely nodose appearance. There is no liquefaction of the medium, and no formation of gas. In stroke cultures there is a thin bluish-white film, but it does not spread to such an extent as in the case of the surface growth of a stab culture (Fig. 79, B). In gelatine plates also

FIG. 79.

A. Stab culture of the typhoid bacillus in gelatine, five days growth.
B. Stroke culture of the typhoid bacillus on gelatine, six days' growth.
C. Stab culture of the bacillus coli in gelatine, nine days' growth; the gelatine is split in its lower part owing to the formation of gas.

the superficial and deep colonies present corresponding differences. The former are delicate semi-transparent films, with wavy margin, and are much larger than the colonies in the substance, which appear as small round points. These appearances, which are well seen on the third or fourth day, resemble those seen in agar plates, as already

described in the method of isolation; but on gelatine the surface colonies are rather more transparent than those on agar. Their characters, as seen under a low power of the microscope, also correspond.

In stroke cultures on *agar* there is a bluish-grey film of growth, with fairly regular margins, but without any characteristic features. This film is loosely attached to the surface, and can be easily scraped off.

The growth on *potatoes* is most important. For several days (at ordinary temperature) after inoculation there is apparently no growth. If looked at obliquely, the surface appears wet, and if the surface is scraped with the platinum loop, a glistening track is left, and a cover-glass preparation shows abundant growth. Later, however, a slight pellicle with a dull, somewhat velvety surface, may appear, and this may even assume a brown appearance. These characteristic appearances are only seen when a fresh potato with an acid reaction has been used.

On *bouillon* incubated at 37° C. for twenty-four hours, there is simply a uniform turbidity. Cover-glass preparations made from such sometimes show filamentous forms of considerable length, without apparent segmentation.

Conditions of Growth, etc.—The optimum temperature of the typhoid bacillus is about 37° C., though it also flourishes well at the room temperature. It will not grow below 9° C. or above 42° C. Growth takes place in anærobic as well as in aërobic conditions. Its powers of resistance correspond with those of most non-sporing bacteria. It is killed by exposure for half an hour at 60° C., or for two or three minutes at 100° C. Typhoid bacilli kept in distilled or in ordinary tap water have usually been found to be dead after three weeks (Frankland).

The Bacillus Coli Communis.—This bacillus is the chief organism present in the small intestine in normal conditions, and, with many other bacteria, it also inhabits the large intestine. During typhoid fever, and other pathological conditions affecting the intestines, it is relatively and absolutely enormously increased in the latter situation, where it

may sometimes be almost the only bacillus present. Its relations to various suppurative and inflammatory conditions are described in the chapter on Suppuration (p. 157). Microscopically it has the same appearances and staining reaction as the typhoid bacillus, and like the latter also presents variations in size, though it is usually somewhat shorter (Fig. 80). It is motile, and possesses lateral flagella, which, however, are fewer in number and somewhat shorter than those of the typhoid bacillus. It is easily isolated from the stools of men and animals by any of the ordinary methods. After, *e.g.*, twenty-four hours' incubation at 37° C. on agar, there are large surface colonies and smaller substance colonies on the plates. To the naked eye they are denser and more glistening than those of typhoid when viewed by transmitted light, and rather of a brownish-white colour. Under a low objective the colonies again appear denser than those of the typhoid bacillus, and more granular. On ordinary gelatine and agar media the appearances are similar to those of the typhoid bacillus, but the growth is whiter, thicker, and more opaque, and gives the impression of having greater vigour. In the case of gelatine stab cultures, a few gas bubbles sometimes develop in the medium (Fig. 79, C). On potatoes in forty-eight hours there is a distinct brown pellicle, with a dull surface. This contrasts very markedly with the colourless film of the B. typhosus.

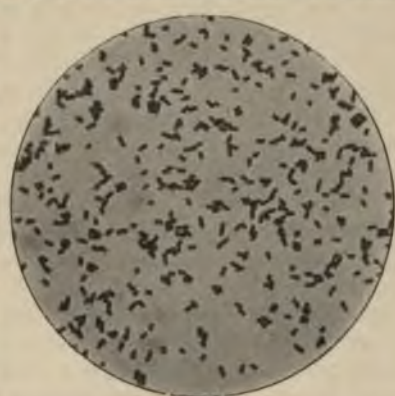

FIG. 80.—Bacillus coli communis. Film preparation from a young culture on agar. Stained with weak carbol-fuchsin. × 1000.

The Comparative Culture Reactions of the B. typhosus and the B. coli.—The importance of the relationships between the B. typhosus and the B. coli has caused great attention to be paid to their biological characters, in order to facilitate the distinction of the one from the other. Some of these we have already noted. Of the morphological characters the growth on potatoes is the most important. It has been pointed out by Wathelet, and also by Klein, that differences exist in the growth of the two bacilli in melted gelatine. A gelatine tube is inoculated, and, instead of being kept at the room temperature, is placed in the incubator at 37° C., at which temperature it is of course fluid. These observers point out that in such cultures, in the case of the B. typhosus, there is a general turbidity of the gelatine, while with the B. coli there are great flocculi developed which float on the surface. This observation we have confirmed. It is, however, to physiological differences between the bacilli, rather than to morphological, that importance is to be attached. Several important points are to be studied hereon.

1. *The fermentation of sugars.*—Among the earlier investigators of this point were Chantemesse and Widal. They found that the B. coli produced an acid fermentation in lactose (milk sugar). The method adopted to prove this was as follows. To tubes of 2 per cent lactose bouillon about 1 gram of sterilised calcium carbonate was added in each case, and the tubes were then sterilised. On inoculating such a tube with B. coli, the acid produced by the fermentation (chiefly lactic acid) acts on the calcium carbonate, setting free bubbles of carbon dioxide which collect on the surface of the liquid. The production of acid in lactose gelatine by the B. coli can also be observed by adding to tubes sufficient blue litmus to make the whole distinctly blue. If a stab culture be made in such a tube, a red colour diffuses out in the gelatine from the line of growth, and bubbles of gas also form.

The fermentation of lactose by the B. coli may also be demonstrated by means of Petruschky's *litmus-whey*. The preparation of this medium,

which is somewhat difficult, is as follows. Fresh milk is slightly warmed, and sufficient very dilute hydrochloric acid is added to cause precipitation of the casein, which is now filtered off. Dilute sodium hydrate solution is added up to, but not beyond, the point of neutralisation, and the fluid steamed for one to two hours, by which procedure any casein which has been converted into acid albumin by the hydrochloric acid, is precipitated. This is filtered off, and a clear, colourless, perfectly neutral fluid should result. Its chief constituent, of course, will be lactose. To this, 5 per cent of a saturated alcoholic solution of litmus is added, the medium is put in equal quantities into tubes and then sterilised. After growth has taken place, the amount of acid found can be estimated by dropping in standardised soda solution, till the tint of an uninoculated tube is reached.

By any of these media the undoubted capacity of the B. coli to ferment lactose can be demonstrated. According to the first results of Chantemesse and Widal, the B. typhosus did not ferment lactose. Petruschky, however, states that it can do so. Much seems to depend upon what other constituents are present in the medium. Petruschky noticed its acid-producing powers in litmus-whey. Péré has confirmed the earlier view, but finds that the typhoid bacillus, though it cannot ferment cane sugar or lactose, can originate such a change in arabinose, galactose, levulose, and glucose. The fermentative power of the typhoid bacillus is thus, though existent, much less active than that of the B. coli; and as a matter of practical experience the formation of bubbles of gas in Chantemesse and Widal's lactose medium is rarely observed. The test may, therefore, be taken in conjunction with others, as of use in diagnosing the identity of the bacillus.

Curdling of Milk by the B. Coli.—This probably depends on the fermentation of the lactose of the milk, and the throwing down of the casein by the resulting lactic acid; but the action may be a more complicated one, as milk can be curdled by organisms which do not possess acid-forming properties. To apply this test 10 c.c. of milk are put in a series of test-tubes and sterilised by steaming at 100° C. It will be found here that the B. coli curdles milk, while the B. typhosus does not.

Formation of Acids in Ordinary Media.—If ordinary

litmus bouillon or gelatine be inoculated with the B. typhosus or the B. coli, a production of acid will be observed during the early period of growth, but the acid reaction is more quickly produced by the B. coli.

With such media Péré found that in the case of both microbes there was for forty-eight hours a production of acid. At the end of five days, however, typhoid cultures were alkaline, and in cultures of B. coli the acidity, though present, was diminished. Ordinary media contain sugars derived from the meat of which they are made, and the acidity might proceed from the fermentation of these. With media made with pure syntonin or peptone, though there was an initial slight acid formation, especially with the B. coli, still in the case of both organisms at the end of four days the reaction was alkaline. The reaction is, therefore, probably a double one, but the resulting acidity in ordinary cases may be due to fermentative changes in carbohydrates. Here again the acid-forming capacities of the B. typhosus are inferior to those of the B. coli.

(2) *Production of Gas by the B. coli.*—If a liquefied gelatine tube be inoculated, shaken, and allowed to solidify, a so-called "shake culture" is produced. The colonies develop *in situ*, and round each a bubble of gas forms, causing a little split in the gelatine. According to Klein this gas is methane. No such development of gas occurs in a shake culture of typhoid. The occasional formation of bubbles of gas by the B. coli in ordinary stab cultures in gelatine has already been mentioned.

(3) *Formation of Indol.*—Indol is a body belonging to the aromatic series, and related to the phenols. It occurs naturally in the lower parts of the human intestinal tract, and is formed by the splitting up of peptone under the influence of putrefactive bacteria. Among the latter is to be classed the B. coli. The B. typhosus has no such effect. Indol can be recognised in bouillon cultures of the B. coli three to four days old by the following test: To the culture a little solution of potassium nitrite (according to Kitasato best 1 c.c. of a .02 per cent solution) is added. On now dropping in a little concentrated sulphuric acid, there is observed a pink coloration caused by the formation of a compound of indol and nitrous acid. Instead of potassium

nitrite and sulphuric acid, yellow nitric acid (which of course contains nitrous acid) may be employed alone. The typhoid bacillus never gives this reaction, and all are agreed that this is one of the most valuable differential tests between the two bacilli. The only fallacy to which it appears liable, is that while the B. typhosus never gives it, it appears that some varieties of the B. coli fail to produce it also. Attention must be directed to one important point. We have found that, as in the case of this same indol test for cholera, great care must be taken in the selection of the peptone in preparing the bouillon to be used. Not every specimen of commercial peptone will give the reaction. A series of peptones must, therefore, be tested, and when a sample is obtained which gives the reaction well, it must be preserved for subsequent use for the same purpose. We may here say in conclusion that indol is not produced by the B. coli in the presence of lactose. The indol reaction must thus not be sought for in a lactose medium.

(4) *Growth on Phenolated Gelatine.*—It was at one time thought that gelatine with .2 per cent carbolic acid added inhibited the growth of all bacteria but the typhoid bacillus. It has been found, however, that the growth of the B. coli is also unaffected by such a medium, though it prevents the growth of most putrefactive organisms which liquefy gelatine.

(5) *Widal's Serum Method for Distinguishing B. typhosus from B. coli.*—This will be described later (p. 322), and here we need only say that it is probably the most important means of distinguishing between the two bacilli.

It will thus be seen that the diagnosis between the B. typhosus and the B. coli is a matter of no small difficulty. The points to be attended to in making such a diagnosis are given in the accompanying table. There is no evidence that the one organism ever passes into the other. Klein has found that both after prolonged sojourn in distilled and tap water, and also after passage through the bodies of a series of animals, each organism still preserves its original characters. Statements as to their identity usually rest on theoretical considerations, or on purely negative evidence.

METHODS OF THE DIAGNOSIS OF THE TYPHOID BACILLUS.

The Differences between the B. typhosus and the B. coli :—

B. Typhosus.	*B. Coli.*
Flagella more numerous, longer, and more wavy.	Flagella fewer and shorter.
In artificial media growth generally slower and not so vigorous.	Growth faster and more vigorous.
Growth on fresh acid potatoes, a nearly transparent film.	Growth on potatoes, a brown pellicle.
Very slight acid production in ordinary media, followed sometimes by production of alkali.	Well-marked acid production.
Fermentation of lactose very slight if any.	Fermentation pronounced.
Milk not coagulated.	Milk coagulated.
Gelatine shake cultures—no gas formation.	Abundant gas formation round colonies.
Production of indol in ordinary bouillon—nil.	Well-marked indol production (in some varieties none—Klein).
Widal's reaction. Bacilli become clumped together and motionless in the serum of a typhoid patient. (A similar reaction is given by the blood serum of an animal immunised against the typhoid bacillus).	Bacilli remain actively motile.

Pathological Changes in Typhoid Fever.—As these are sufficiently described in ordinary pathological text-books, we can confine our attention solely to their bacteriological aspects. It is generally recognised that the inflammation and ulceration in the *Peyer's patches and solitary glands of the intestine* are the central features of the disease. In the early stage of this disease there is to be observed with the naked eye a swollen and slightly pinkish appearance of the patches and lymphoid tissue of the intestine. From the study of the histological appearances in such patches and in the lymphoid tissue, it is seen that there has been produced an acute inflammatory condition, attended with

extensive leucocytic emigration, and sometimes small hæmorrhages may be observed. It is at this period that the typhoid bacilli are most numerous in the patches, groups, occurring between the cells, being easily found. There now takes place a necrosis of the cells which may involve the whole tissue of the patch, and a slough forms which, being cast off, leaves an ulcer. This necrosis is evidently in chief part the result of the action of the toxic products of the bacilli, which now gradually disappear from their former positions, though they may still be found invading the deeper tissues and at the spreading margin of the necrosed area. They are also described as occurring in the lymphatic spaces of the muscular coat. It is important to note that the ulcers in a fatal case of typhoid may vary much in numbers. The whole lower third of the small intestine may be ulcerated, or only two or three ulcers may be present even in a case where death has occurred by exhaustion. Further, small ulcers may also occur in the lymphoid follicles of the large intestine.

The condition of the *mesenteric glands* in typhoid is important. Those corresponding to the affected part of the intestine are usually enlarged, sometimes to a very great extent, the whole mesentery being filled with glandular masses. In such glands there may be acute inflammation attended with hæmorrhages, and even necrosis in patches may occur, but this is never the outstanding feature as in the case of the Peyer's patches. Sometimes on section the glands are of a pale-yellowish colour, the contents being diffluent and consisting largely of leucocytes. Typhoid bacilli may be isolated both from the glands and the lymphatics connected with them, but here the B. coli is in addition often present.

The *spleen* is enlarged,—on section usually of a fairly firm consistence, of a reddish-pink colour, and in a state of acute congestion. Of all the solid organs it usually contains the bacilli in greatest numbers. They can be seen in sections, occurring in clumps between the cells. There is no evidence of local reaction round these clumps. Similar

clumps occur in the *liver* in any situation, and without any local reaction. Here, however, there are often small foci of leucocytic infiltration, in which, so far as our experience goes, bacilli cannot be demonstrated. Clumps of bacilli may also occur in the *kidney*.

In addition to these local changes in the solid organs there are also widespread *cellular degenerations*. These usually take the form of cloudy swelling of the specialised cells of the liver and kidney, or of the muscular fibres of the heart. A granular disintegration of such cells may occur. As they may exist altogether apart from local presence of the bacilli, these changes suggest the circulation in the blood of soluble poisons.

In the *lungs* there may be patches of congestion and of acute broncho-pneumonia. In these, typhoid bacilli may sometimes be observed, but evidence of a toxic action depressing the powers of resistance of the lung tissue is found in the fact that the pneumococcus is frequently found in such complications of typhoid fever.

The *nervous system* shows little change, though meningitis associated either with the typhoid bacillus, with the B. coli, or with the streptococcus pyogenes has been found.

The typhoid bacilli probably travel by the blood stream, but they have not been frequently isolated from the *blood*. Whether they have ever been found in the *roseolar spots* which occur in typhoid fever is a subject of dispute. The fact that the typhoid bacilli are usually confined to certain organs and tissues, shows that they must have a selective action on certain tissues.

To sum up the pathology of typhoid fever we have in it a disease, the centre of which lies in the lymphatic tissue in and connected with the intestine. In this situation we must have an irritant, against which the inflammatory reaction is set up, and which in the intestine is sufficiently powerful to cause necrosis. The affections of the other organs of the body suggest the circulation in the blood of poisonous substances capable of depressing cellular vitality, and producing histological changes.

Suppurations occurring in connection with Typhoid Fever.—The relation of the typhoid bacillus to such conditions has been the subject of much discussion, and it must be observed at the outset that statements as to its isolation from pus, etc., can be accepted only when all the

points available for the diagnosis of the organism have been attended to. On this understanding the following summary may be given. In a small proportion of the cases examined the typhoid bacillus has been the only organism found. This has been the case in suppurative periostitis, suppuration in the parotid, abscesses in the kidneys, etc., and probably also in one or two cases of ulcerative endocarditis. But in the majority of cases, other organisms, especially the B. coli and the pyogenic micrococci, have been obtained, the typhoid bacillus having been searched for in vain. It has, moreover, been experimentally shown, notably by Dmochowski and Janowski, that suppuration can be experimentally produced by injection in animals, especially in rabbits, of pure cultures of the typhoid bacillus, the occurrence of suppuration being favoured by conditions of depressed vitality, etc. These observers also found that when typhoid bacilli were injected along with pyogenic staphylococci, they died out in the pus more quickly than the latter. So that in clinical cases where the typhoid bacillus is present alone, it is improbable that other organisms were present at an earlier date.

Pathogenic Effects produced in Animals by the Typhoid Bacillus.—There is no disease known to veterinary science which can be said to be identical with typhoid, nor is there any evidence of the occurrence of the typhoid bacillus under ordinary pathological conditions in the bodies of animals. Even before any bacteriological investigation, unsuccessful attempts had been made to communicate the disease to animals by feeding them on typhoid dejecta, and we have seen that Gaffky did not succeed in communicating the disease to animals by feeding them with bacilli, though many different species were inoculated. We have therefore to recognise as an initial difficulty the fact that animals are not susceptible to the disease, at least in the form it assumes in man. Nevertheless various observers have succeeded in producing pathogenic effects. Typhoid bacilli are killed by a very short exposure to the gastric juice, and Beumer and Peiper, taking this into account, applied the method devised

by Koch to overcome the same difficulty in the case of the cholera vibrio, namely, the neutralisation of the gastric juice with soda before the introduction of the bacteria, and the slowing of the intestinal peristalsis with opium (*vide* chapter on Cholera). These observers succeeded by this method in causing death in rabbits and guinea-pigs. They, as well as others, also caused death by intraperitoneal, intravenous, and subcutaneous injections of pure cultures. In animals thus inoculated there were, in a few hours, restlessness, swelling of the abdomen, pyrexia, and gradually increasing weakness, with death in twelve hours to four or five days. *Post mortem* there were swelling of the spleen, congestion of the liver and kidneys, hyperæmia especially of the upper part of the intestine. Some observers found swelling and even occasionally ulceration of Peyer's patches. The typical typhoid lesions, however, were not reproduced. The distribution of the bacilli varied with the seat of introduction. If introduced into the blood stream they were found throughout the body, but especially in the spleen; if introduced into the peritoneum they were found chiefly in the spleen and liver. Sirotinin showed that dead cultures produced the same effects, and Wyssokowitch observed that living bacilli injected into the peritoneum rapidly decreased in numbers, though still present, *e.g.*, in the spleen. Many, therefore, held that there was no evidence that the bacilli multiplied in the blood, and considered that the effects were due to toxic bodies injected along with the bacilli. Other observers did not confirm Sirotinin's results with the injection of dead cultures, and Pfeiffer is probably correct in holding that the diverse results obtained were due to differences in the virulence of the cultures used. Such differences in virulence can be produced artificially, and an artificial exaltation of this virulence forms the basis of the important work of Sanarelli.

Sanarelli starts with the statement that most ordinary laboratory cultures are either entirely non-pathogenic, or pathogenic only on the intraperitoneal injection of large doses. The virulence can be exalted in various ways. He

found, however, the following to be the most efficacious procedure.

.5 c.c. of a bouillon typhoid culture twenty-four hours old was injected subcutaneously into a guinea-pig, and at the same time 10 to 12 c.c. of sterilised old culture of B. coli were introduced into the peritoneal cavity. The animal died in from twelve to fourteen hours with typhoid bacilli in the peritoneum and a few in the blood and organs. From the former situation bouillon cultures were made and used for the subcutaneous injection of a second animal, which also received intraperitoneally some sterilised B. coli culture, a less quantity of the latter being now found sufficient to cause death in the same time. In a series of animals thus inoculated, each from the previous member, less and less B. coli culture was found sufficient until this could be dispensed with altogether, the typhoid bacilli alone being sufficient. After about thirty such passages a culture of a typhoid bacillus of exalted virulence was obtained.

The intraperitoneal injection of a few drops of such a culture of highly-exalted virulence, or the subcutaneous injection of 3 to 4 c.c., caused in guinea-pigs and rabbits illness and death in from twelve to twenty-four hours. After injection the temperature first rose and then gradually sank till death, and there were flatulence and abdominal tenderness. *Post mortem* the spleen was enlarged and hæmorrhagic, the liver enlarged and fatty, the kidneys congested, whilst the intestine showed congestion, with excess of mucous secretion and swelling of the lymphoid patches. There was desquamation of the intestinal epithelium. The Peyer's patches were enormously infiltrated, sometimes almost purulent, and, where the inoculation had been intraperitoneal, they contained typhoid bacilli. These were also found in the mesenteric lymphatics and glands, and in the spleen, where they occurred in groups in the pulp but not in the Malpighian bodies. Sanarelli insists that by whatever path the bacilli were introduced into the body the brunt of the pathological effects always fell on the intestine and abdominal organs; and with regard to the bacilli themselves, though they might be found in the blood, their usual site was in the solid organs, especially the spleen. Pfeiffer, criticising

Sanarelli's work, could not confirm the observations of the latter with regard to a special affection of the Peyer's patches, but this result may be due to the fact that the cultures used by him did not possess so exalted a virulence as those of Sanarelli. The observations of Sanarelli, at any rate, leave no doubt that, provided the cultures be sufficiently virulent, the typhoid bacillus can multiply in the body of an animal and rapidly produce a fatal result. Before we discuss the significance of its pathogenic effects in animals we must look at what has been done in investigating the toxic bodies, which the pathological anatomy of the disease leads us to suspect are elaborated by the bacillus typhosus.

The Toxic Products of the Typhoid Bacillus.—Brieger, in his earlier work on the ptomaines, stated that bouillon cultures of the typhoid bacillus eight weeks old contained a base to which he assigned the formula $C_7H_{17}NO_2$, and gave the name *typhotoxin*. As we have seen in the chapter on the general pathological effects of bacteria, Brieger's earlier work is open to objection, and his observations on this particular body have not been confirmed, nor, indeed, did the physiological effects of typhotoxin throw any light on the pathology of typhoid fever. Brieger did not follow up his own results, for later (1890), in the paper published by Fraenkel and himself he brings forward quite other toxic bodies formed by the typhoid bacillus. The new body belongs to the group of toxalbumins. The authors obtained it by making bouillon cultures germ-free, by filtering through a Chamberland's filter after concentration to one-third of the original volume by evaporation at 30° C. A precipitate was then obtained by adding ten volumes of alcohol acidified with acetic acid. The precipitate was redissolved in water and reprecipitated with alcohol, again dissolved in water and again precipitated by saturating with sulphate of ammonium in powder. The precipitate was a third time dissolved in water and dialysed. What remained in the dialyser was the toxic body. It gave the reactions of the group of toxalbumins,

and was energetic in pathogenic effects. These, however, still did not reproduce in entirety the appearances seen either in the natural or artificial disease.

In view of the uncertain results thus obtained in the search for the toxines of typhoid in a pure condition, later observers have been content to work with fluids containing these toxines in mixture with other bodies. Sanarelli, in fact, conjectures that various bodies may be concerned in the toxic action to be inquired into. This observer, in addition to his other work, investigated this toxic action. He prepared the toxine by growing the bacillus the virulence of which he had exalted, as already described, on 2 per cent glycerine bouillon for one month at 37° C. and eight months at the room temperature. It was then kept for some days at 60° C. to kill and macerate the bacilli. A clear fluid could be decanted off which contained the toxic substances, many being no doubt derived from the bacterial bodies. When injected subcutaneously into guinea-pigs in the proportion of 1.5 c.c. per 100 grm. of body weight, it causes death in twenty hours. There is no initial rise of temperature such as occurs when the bacilli are injected, but a progressive fall. There is abdominal distention, pain and bloody stools, with progressive coma and death. *Post mortem*, there is peritoneal exudation rich in leucocytes and an enlarged spleen. The intestine is congested, especially the small intestine, and the contents serous and bloody. The mucosa is rough and the lymphatic patches infiltrated and congested. The other organs are normal. There is thus some reason for believing that many of the local as well as the general pathological appearances are due to toxic products which the typhoid bacillus is capable of forming. With regard to these toxic products Pfeiffer has shown that they are probably present only in the bodies of the bacilli, and are not excreted into a medium in which the bacilli may be growing. This is indicated by the fact that cultures filtered bacteria-free are almost non-toxic. In order to study the toxic effects, the bodies of the bacilli which have been killed by one

hour's exposure to a temperature of 60° C., must be employed. In the work of Brieger and Fraenkel, attended as it was with unsatisfactory results, this mode of procedure was not employed.

The Immunisation of Animals against the Typhoid Bacillus.—In considering this difficult question the reader must note (1) immunisation against the living bacilli; (2) immunisation against their toxines; and (3) the relations between these two conditions. Earlier observers had been successful in accustoming mice to the typhoid bacillus by the successive injections of small and gradually increasing doses of living cultures of the bacillus. Later, Brieger, Kitasato, and Wasserman, in their joint researches on immunity, obtained further results. One of the general principles on which they worked was that a bouillon made from an extract of the thymus gland contained bodies which were inimical to the virulence of various bacilli, though the medium was sufficiently nutritive to permit of their multiplication. Applying this principle to the B. typhosus, they grew a culture very virulent to mice for three days on such a bouillon, and then killed the contained bacilli by heating at 60° C. for fifteen minutes. A small quantity was then injected into each of a series of mice without fatal effect. Ten days later it was found that these mice could tolerate an otherwise fatal dose of the original living virulent culture. The experiments were repeated on guinea-pigs with a similar result, and it was also found that the serum of a guinea-pig thus immunised could, if transferred to another guinea-pig, protect the latter from the subsequent injection of a dose of typhoid bacilli to which it would naturally succumb. Chantemesse and Widal, Sanarelli, and also Pfeiffer, succeeded in immunising guinea-pigs against the subsequent intraperitoneal injection of virulent living typhoid bacilli, by repeated and gradually-increasing intraperitoneal or subcutaneous doses of typhoid cultures in bouillon, in which the bacilli had been killed by heat or chloroform vapour. Experiments performed with serum derived from typhoid patients and convalescents have been adduced as bearing

on the matter. Many observers had noticed that the serum of men convalescent from typhoid had an inimical effect on typhoid bacilli; and these results have been confirmed by Pfeiffer, whose technique was less open to objection than that of most previous workers. He found that the serum of healthy men had such an action but in a much less degree. The method was to mix the serum and the bacilli in a little bouillon, and inject the whole intraperitoneally into guinea-pigs. He found that when the latter did not die, the bacilli became motionless and apparently dead, and that plate cultures made after a time from the exudation containing them, remained sterile. The serum of such patients has, therefore, *antimicrobic* powers, but there is no evidence that it contains any antitoxic bodies (see chapter on Immunity). Pfeiffer, for example, found that on adding serum from typhoid convalescents to the typhoid toxines, and injecting the mixture into guinea-pigs, death took place as in control animals which had received the toxines alone. Sanarelli also found that while the injection of toxines obtained as above described, rendered the animal immune to a certain dose of living bacilli, it still could be killed by a further dose of the toxine. He does not, however, give the doses employed. Pfeiffer found that by using the serum of immunised goats he could, to a certain extent, protect other animals against the subsequent injection of virulent living typhoid bacilli. On trying to use the agent in a curative way, *i.e.*, injecting it only after the bacilli had begun to produce their effects, he got little or no result.

There is thus abundant evidence that the serum of persons who have recovered from typhoid fever, and the serum of animals artificially immunised against virulent typhoid bacilli, protect from these bacilli. There is no evidence that the serum has much power in neutralising the products of these bacilli. We have thus this curious fact. Animals are immunised by injections of the toxines of a bacillus; their serum, however, has no effect in neutralising its toxines, but only aids in the destruction of the

bacilli which produce the toxines. Similar results have been obtained in the case of cholera. It therefore appears that the toxines of the typhoid bacillus stimulate the tissues of an animal to produce bodies which act, directly or indirectly, as germicides to the bacilli. What these are, when and how they are produced, we do not at present definitely know.

The Pathogenicity of the B. coli and its Relation to that of the Typhoid Bacillus.—We have already seen that the B. coli is probably responsible for the occurrence of some of the abscesses which follow typhoid fever. It is also apparently the cause of many cases of summer diarrhœa (cholera nostras), and of infantile diarrhœa. Its numbers in the intestine are greatly increased during typhoid fever, and also during any pathological condition affecting the intestine. Intraperitoneal injection in guinea-pigs is occasionally fatal. Subcutaneous injection results in local abscesses, and sometimes in death from cachexia. Sanarelli found that the B. coli isolated from typhoid stools was much more virulent than when isolated from the stools of healthy persons. He holds that the increase in virulence is due to the effect of the typhoid toxines, and devised an ingenious experiment which seems to prove this point. This increased virulence of the B. coli in the typhoid intestine makes it possible that some of the pathological changes in typhoid may be due, not to the typhoid bacillus, but to the B. coli. Some of the general symptoms may be intensified by the absorption of toxic products formed by it and by other organisms. The question has been raised as to whether the lesions produced in guinea-pigs by such virulent B. coli can be distinguished from those of the B. typhosus. Sanarelli holds that they can, and that the former partake more of the nature of a septicæmia with pleurisy, pericarditis, and peritonitis; while in the latter the disease is more concentrated in the lymphatic tissue of the intestine. He admits, however, that the differences are more in degree than kind. Differences of behaviour of the two bacilli in connection with their pathological effects, have been brought forward as confirmatory of the fact of their being distinct species. Thus Sanarelli accustomed the intestinal mucous membrane of guinea-pigs to toxines derived from an old culture of the B. coli, by introducing day by day small quantities of the latter into the stomach. When a relatively large dose could be tolerated, it was found that the introduction in the same way of a small quantity of typhoid toxine was followed by fatal result. Pfeiffer also found that while the serum of convalescents from typhoid paralysed the typhoid bacilli, it had no more effect on similar numbers of B. coli than the serum of healthy men.

General View of the Relationship of the B. typhosus to Typhoid Fever.—1. We have in typhoid fever a disease

having its centre in and about the intestine, and acting secondarily on many other parts of the body. In the parts most affected there is always a bacillus present, microscopically resembling another bacillus (the B. coli) which is a normal inhabitant of the animal intestine. This bacillus can be isolated from the Peyer's patches, from the mesenteric glands, the spleen, the liver, the kidneys, and has been found elsewhere in the body. When isolated it is now found by culture reactions to present differences which enable it to be distinguished from the B. coli. The whole series of culture reactions, however, must be investigated before a particular bacillus is identified as the B. typhosus, and no weight must be attached to any observations made on the subject when this has not been done. There are undoubtedly very many cases where organisms have been isolated from various sources resembling closely the B. typhosus on the one hand, and the B. coli on the other, but differing from one or other in some one particular. Cultures, for instance, which otherwise resemble B. coli may not give an indol reaction. The important point here, however, is that a bacillus giving all the reactions of the typhoid bacillus has never been isolated except from cases of typhoid fever, or under circumstances that make it possible for the bacillus in question to have been derived from a case of typhoid fever. There is no evidence that the B. coli can be transformed into the typhoid bacillus, or the typhoid bacillus into the B. coli, though of course this does not preclude the possibility of the one having been originally derived from the other. All practically are now agreed that two separate bacilli exist, the B. coli and the B. typhosus.

2. Against the etiological relationship of the latter to the disease several facts may be adduced. First, there is the comparative difficulty of the isolation of the B. typhosus from the stools of typhoid patients. We have pointed out, however, that the latter can be isolated during the first ten days of the disease, and that the extraordinary multiplication of the B. coli, which takes place in any pathological

condition of the intestine, sufficiently explains the failures in the latter stages. The second and great difficulty in the way of accepting the etiological relationship of the B. typhosus lies in the failure to cause the disease in animals. We have noted, however, that there is no evidence that animals are susceptible to the disease. The experiments of Sanarelli ought to have considerable weight in this connection. No other observer has exalted to such a degree the virulence of the typhoid bacillus, which is certainly the rational procedure when dealing with a refractory animal. In a way this is unfortunate, for at present Sanarelli's results can be neither confirmed nor denied. We must for the present provisionally accept his statements that both the bacilli of exalted virulence, and what is even more important, the toxines derived from them, give rise to selective pathological changes in Peyer's patches and the mesenteric glands.

3. The observations of Pfeiffer and others on the protective power against typhoid bacilli shown, on testing in animals, to belong to the serum of typhoid patients and convalescents, and the peculiar action of such serum in immobilising and causing clumping of the bacilli (*vide infra*) are also of great importance. Especially is this the case when these are taken in conjunction with the fact that the reactions apply only to the typhoid bacillus, and not to other organisms, including the varieties of the B. coli, which resemble it in growth characters, etc. These very important facts may thus be accepted as indirect evidence of the pathogenic relationships of the typhoid bacillus to the disease.

There is much knowledge yet to be acquired before absolute proof can be obtained, and there is abundant room for discoveries which may modify many of our present views on the bacteriology of the disease; but according to our present results we must hold that the bacillus typhosus constitutes a distinct species of bacterium, and that it is the cause of typhoid fever.

The Serum Diagnosis of Typhoid Fever.—This method was discovered independently by Widal and Grünbaum in

1896 (the former having priority by some weeks), and has already been tested on an extensive scale. The researches which led up to this discovery, and the principle on which it depends, are discussed in the chapter on Immunity. The method is based upon the fact that living and actively motile typhoid bacilli, if placed in the diluted serum of a patient suffering from typhoid fever, within a very short time lose their motility and become aggregated into clumps. It would appear that in the progress of the disease certain antagonistic bodies are developed in the blood of the patient, which have a paralysing or devitalising action on the typhoid bacilli. To carry out the method, the two things required are (*a*) a fluid containing the bacilli in a very actively motile condition, and (*b*) the diluted blood serum. With regard to the first, either a bouillon culture, preferably not more than twenty-four hours old (certainly not more than forty-eight hours old), should be used; or a small portion of an agar culture of the same age may be added to a few drops of bouillon in a watch-glass, so as to produce a uniform emulsion. It is useful to note that sufficient growth for the purpose may be obtained within six hours by making a fresh subculture on agar, and incubating at 37° C.; in such a growth all the bacilli are extremely motile. For the purpose of obtaining the diluted serum several methods have been adopted. The following, used by Delépine, will be found very convenient. A small glass tube, of diameter about one-eighth of an inch, is taken, and two constrictions about half an inch apart are made by heating and drawing out in a flame. In this way a small bulb is formed. The tube is then broken at one of the constrictions and is ready for use. The skin of the patient having been cleansed and dried, a prick is made in the usual way and a drop of blood obtained, which is sucked up into the small bulb. When to be used for transport, the bulb is broken off at the constrictions and the two ends are sealed in the flame. After a time the blood, of course, coagulates within the bulb, but a drop of blood-stained

serum can be blown out. To make the proper dilution, a clean cover-glass is taken, and on this are placed at separate points nine drops of the bouillon containing the bacilli. These drops are conveniently measured by a small platinum loop. At another point on the cover-glass a similar drop of the blood or serum is placed, and the mixture is then made. In this way the serum is diluted in the proportion of 1 : 10. The drop is then placed on a slide and examined under the microscope.

We may mention another method which we have found very convenient, but which requires a glass pipette, by which a dilution is made of 1 : 10. (We use a leucocytometer pipette for this purpose.) The blood is drawn up to the mark 1 and bouillon is sucked after it up to the mark 11, the mixing being then effected in the bulb by shaking from side to side. The mixture is then blown into a U-shaped tube of bore about an eighth of an inch, the length of the limbs being about three inches. Such a tube is very easily made by taking a piece of quill glass tube about six inches in length, carefully heating the centre in a Bunsen flame, and then bending till the two halves are parallel to one another. (Many such tubes can be rapidly made at one time.) The U-shaped tube containing the mixture is then centrifugalised. The result is that all the corpuscles are collected in a thick mass at the bend, the limbs of the tube containing a clear fluid composed, of course, of the diluted serum. The diluted blood can be used without separating the red corpuscles, but it is preferable that this should be done. If a centrifuge is not available, a considerable amount of separation may be obtained by allowing the tube to stand in the vertical position for a couple of hours. A small quantity of the diluted serum is taken by means of a narrow glass pipette and placed on a slide, a slide with hollow cell being preferable (*vide* Fig. 25, B). To this is added about half its quantity of the bouillon containing the bacilli, and the two drops are mixed together. The cover-glass is then placed in position, and the specimen is examined. By this method the

ultimate dilution will be approximately 1 : 15, and this is the proportion generally to be recommended.

If a preparation made by either of these methods is examined at once under the microscope, the bacilli will usually be found to be actively motile, darting about in all directions. In a short time, however, if the serum is that of a patient suffering from typhoid, their movements gradually become slower, the bacilli begin to adhere to one another, and ultimately become immobile and form clumps by their aggregation. When the latter stage is reached the reaction is said to be complete. The time required varies in different cases; in some the movements are effected almost instantaneously, in others not for some minutes, and the clumping is usually well marked within half an hour, though occasionally it takes longer.

A corresponding reaction, visible to the naked eye, may be obtained by placing the mixture, composed of typhoid serum and of bouillon containing the typhoid bacilli, in a slender glass tube, and allowing it to stand in the upright position. At the end of twenty-four hours the bacilli form a mass at the foot like a precipitate, the upper part of the fluid being clear. A similar preparation, made with normal serum instead of typhoid serum, gives a diffuse turbidity at the end of twenty-four hours. This test is usually called the "sedimentation test." It has the disadvantage of taking longer than the microscopic method, but is useful as a control; in nature it is similar.

The reaction given by the serum in typhoid fever usually begins to be observed about the seventh day of the disease, though occasionally it has been found as early as the fifth day. It gradually becomes more marked as the disease advances, and it is still given by the blood of convalescents from typhoid. How long it lasts after the end of the disease has not yet been fully determined, but in many cases it has been found after several months at least. As a rule the reaction is more marked where the fever is of a pronounced character. In the milder cases it is less pronounced.

The results of a great many independent observers, with which our own agree, go to show that this is a specific reaction, occurring only in typhoid fever, and that the test is one of great value in diagnosis. In applying it, however, a control specimen should always be made with normal blood treated in the same way, at least till the observer is quite familiar with the details of the method. It is interesting to note that the reaction is not given when the B. coli is used instead of the typhoid bacillus, the serum of patients suffering from typhoid fever having no more effect on the former organism than normal serum. It may be again pointed out that this forms additional evidence that the typhoid bacillus is really the causal agent in the disease, and furnishes an additional test by which cultures of the two organisms can be distinguished.

Methods of Examination.—The methods of microscopic examination, and of isolation of typhoid bacilli from the spleen *post mortem*, have already been described. They may be isolated from the Peyer's patches, lymphatic glands, etc. by a similar method.

During life, typhoid bacilli may be obtained in culture in the following ways :—

(*a*) *From the Spleen.*—This is the most certain method of obtaining the typhoid bacillus during the continuance of a case. The skin over the spleen is purified and, a sterile hypodermic syringe being plunged into the organ, there is withdrawn from the splenic pulp a droplet of fluid, from which plates are made. In a large proportion of cases of typhoid the bacillus may be thus obtained, failure only occurring when the needle does not happen to touch a bacillus. Numerous observations have shown that provided the needle be not too large, the procedure is quite safe. Its use, however, is scarcely called for.

(*b*) *From the Urine.*—Typhoid bacilli are present in the urine in some cases, especially late in the disease, but probably only when there are groups in the kidney substance. The urine may be received (preferably drawn off with a sterile catheter) in a sterile vessel, and plate cultures or successive

stroke cultures on agar tubes, made from it at once. It is better, however, to put a quantity into a sterile test-tube and centrifugalise it. The upper part is then drawn off with a pipette, and cultures made as above from the lower part or from the slight deposit which sometimes forms.

(*c*) *From the Stools.*—During the first ten days of a case of typhoid fever, the bacilli can be isolated from the stools by the ordinary plate methods—preferably in phenolated gelatine. After that period, though the continued infectiveness of the disease indicates that they are still present, their isolation is practically hopeless. We have seen that after ulceration is fairly established by the sloughing of the necrosed tissue, the numbers present in the patches are much diminished and therefore there are fewer cast off into the intestinal lumen, and that in addition there is a correspondingly great increase of the B. coli, which thus causes any typhoid bacilli in a plate to be quite outgrown. From the fact that the ulcers in a case of typhoid may be very few in number, it is evident that there may be at no time very many typhoid bacilli in the intestine. We may add that the microscopic examination of the stools is useless as a means of diagnosing the presence of the typhoid bacillus.

Isolation from Water Supplies.—A great deal of work has been done on this subject. It is evident that if it is difficult to isolate the bacilli from the stools it must *a fortiori* be much more difficult to do so when the latter are enormously diluted by water. Some have held that the typhoid bacillus has never been isolated from suspected water, and have adduced this as an argument against its etiological relationship to the disease. The considerations just advanced, however, militate against such a view. The B. typhosus has been isolated from water during epidemics. This was done by Klein in the outbreaks in recent years at Worthing and Rotherham. The B. coli is, as might be expected, the organism most commonly isolated in such circumstances. In the case of both bacteria, the whole series of culture reactions must be gone through before any particular organism isolated is identified as the one or the other;

probably there are saprophytes existing in nature which only differ from them in one or two reactions. In the examination of water, the addition of .2 per cent carbolic acid to the medium inhibits to a certain extent the growth of other bacteria, while the B. typhosus and the B. coli are unaffected. In examining waters, the ordinary plate methods are generally used. Klein, however, filters a large quantity through a Berkefeld filter and, brushing off the bacteria retained on the porcelain, makes cultures. A much greater concentration of the bacteria is thus obtained.

CHAPTER XV.

DIPHTHERIA.

THERE is no better example of the valuable contributions of bacteriology to scientific medicine than that afforded in the case of diphtheria. Not only has research supplied, as in the case of tubercle, a means of distinguishing true diphtheria from conditions which resemble it, but the study of the toxines of the bacillus has explained the manner by which the pathological changes and characteristic symptoms of the disease are brought about, and has led to the discovery of the most efficient means of treatment, namely, the anti-diphtheritic serum.

Historical.—As in the case of many other diseases, various organisms which have no causal relation to the disease were formerly described in the false membrane. The first account of the bacillus now known to be the cause of diphtheria was given by Klebs in 1883, who described its characters in the false membrane, but made no cultivations. It was first cultivated by Löffler from a number of cases of diphtheria, his observations being published in 1884, and to him we owe the first account of its characters in cultures and of some of its pathogenic effects on animals. The organism is for these reasons known as the Klebs-Löffler bacillus, or simply as Löffler's bacillus. By experimental inoculation with the cultures obtained, Löffler was able to produce false membrane on damaged mucous surfaces, but he hesitated to conclude definitely that this organism

was the cause of the disease, for he did not find it in all the cases of diphtheria examined, he was not able to produce paralytic phenomena in animals by its injection, and, further, he obtained the same organism from the throat of a healthy child. This organism became the subject of much inquiry, but its relationship to the disease may be said to have been definitely established by the brilliant researches of Roux and Yersin, who made an extensive study of its characters and life history, and showed that the most important features of the disease could be produced by means of the separated toxines of the organism. Their experiments were published in 1888-90. A considerable amount of further light has been thrown on the subject by the work of Sidney Martin, who has found that there can be separated from the organs in cases of diphtheria substances which act as nerve poisons, and also produce other phenomena met with in diphtheria.

General Facts.—Without giving a description of the pathological changes in diphtheria, it will be well to mention the outstanding features which ought to be considered in connection with its bacteriology. In addition to the formation of false membrane, which may prove fatal by mechanical effects, the chief clinical phenomena are the symptoms of general poisoning, great muscular weakness, tendency to syncope, and albuminuria; also the striking paralyses which occur later in the disease, and which may affect the muscles of the pharynx, larynx, and eye, or less frequently the lower limbs (being sometimes of paraplegic type), all these being grouped together under the term "post-diphtheritic paralyses." It may be stated here that all these conditions have been experimentally reproduced by the action of the bacillus of diphtheria, or by its toxines. On the other hand, there are various secondary inflammatory complications in the region of the throat, such as ulceration, gangrenous change, and suppuration, which may be accompanied by the symptoms of general septic poisoning, and in the production of which other organisms besides the diphtheria bacillus are concerned.

The bacillus of Löffler has now been conclusively proved to be the cause of the disease, and its discovery in the false membrane is practically universally regarded as the only certain means of diagnosis. With the exception of

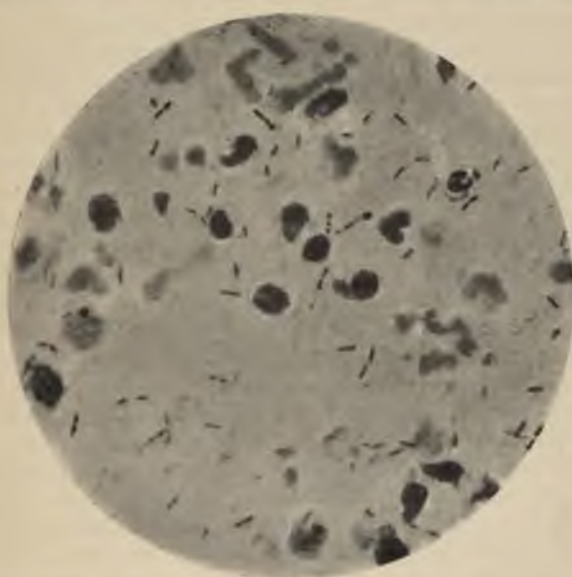

FIG. 81.—Film preparation from diphtheria membrane; showing numerous diphtheria bacilli. One or two degenerated forms are seen near the centre of the field. (Cultures made from the same piece of membrane showed the organism to be present in practically pure condition.)

Stained with methylene-blue. × 1000.

the tubercle bacillus, there is probably no organism which has been the subject of so much routine examination, and the opinion of all who are competent to judge may be said to be unanimous on this subject.

Bacillus Diphtheriæ—*Microscopical Characters.*—If a film preparation be made from a piece of diphtheria mem-

brane (in the manner described below) and stained with methylene-blue, the bacilli are found to have the following characters. They are slender rods, straight or slightly curved, and usually about 3 μ in length, their thickness being a little greater than that of the tubercle bacillus. The size, however, varies somewhat in different cases, and for this reason varieties have been distinguished as small and large, and even of intermediate size. It is sufficient to mention here that in some cases most are about 3 μ in length, whilst in others they may measure fully 5 μ. Corresponding differences in size are found in cultures. They stain deeply with the blue, sometimes being uniformly coloured, but often showing, in their substance, little granules more darkly stained, so that a dotted or beaded appearance is presented. Sometimes the ends are swollen and more darkly stained than the rest; often, however, they are rather tapered off (Fig. 81). In some cases the terminal swelling is very marked, so as to amount to clubbing, and with some specimens of methylene-blue these swellings and granules stain of a violet tint. Distinct clubbing, however, is much rarer than in cultures. There is a want of uniformity in the appearance of the bacilli when compared side by side. They usually lie irregularly scattered or in clusters, the individual bacilli being disposed in all directions. Some may be contained within leucocytes. They do not form chains, but occasionally forms longer than those mentioned may be found, and these specially occur in the spaces between the fibrin as seen in sections.

Distribution of the Bacilli.—The diphtheria bacilli may be found in the membrane wherever it is formed, and may also occur in the secretions of the pharynx and larynx in the disease. It may be mentioned that distinctions formerly drawn between true diphtheria and non-diphtheritic conditions from the appearance and site of the membrane, have no scientific value, the only true criterion being the presence of the diphtheria bacilli. The occurrence of a membranous formation produced by streptococci has already been mentioned (p. 159).

In diphtheria the membrane has a somewhat different structure according as it is formed on a surface covered with stratified squamous epithelium as in the pharynx, or on a surface covered by ciliated epithelium as in the trachea. In the former situation necrosis of the epithelium occurs either uniformly or in patches, and along with this there is marked inflammatory reaction in the connective tissue beneath, attended by abundant fibrinous exudation. The necrosed epithelium becomes raised up by the fibrin, and its interstices are also filled by it. The fibrinous exudation also occurs around the vessels in the tissue beneath, and in this way the membrane is firmly adherent. In the trachea, on the other hand, the epithelial cells rapidly become shed, and the membrane is found to consist almost exclusively of fibrin with leucocytes, the former arranged in a reticulated or somewhat laminated manner, and varying in density in different parts. This membrane lies upon the basement membrane, and is less firmly adherent than in the case of the pharynx.

The position of the diphtheria bacilli varies somewhat in different cases, but they are most frequently found lying in oval or irregular clumps in the spaces between the fibrin, towards the superficial, that is, usually, the oldest part of the membrane (Fig. 82). There they may be in a practically pure condition, though streptococci and occasionally some other organisms may be present along with them. They may occur also deeper, but are rarely or never found in the fibrin around the blood vessels. They may be also seen lying in large numbers on the surface of the membrane, but are there usually accompanied by numerous other organisms of various kinds. Occasionally a few bacilli have been detected in the lymphatic glands. As Löffler first described, they may be found after death in pneumonic patches in the lung, this being a secondary extension in fatal cases. They have also been found by various observers to be occasionally present in the spleen, liver, and other organs after death. This occurrence is probably to be explained by an entrance into the blood stream shortly before

death, similar to what occurs in the case of other organisms, *e.g.*, the bacillus coli communis. With these exceptions, however, it may be stated that the bacillus of diphtheria occurs only locally in the false membrane and in the fluids

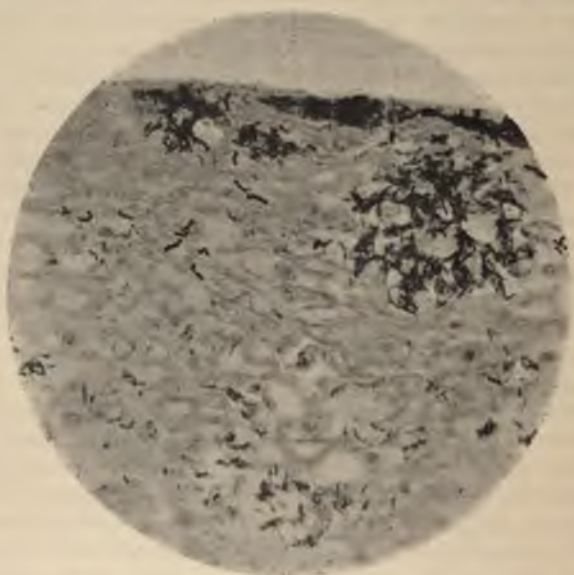

FIG. 82.—Section through a diphtheritic membrane in trachea, showing diphtheria bacilli (stained darkly) in clumps, and also scattered amongst the fibrin. Some streptococci are also shown, towards the surface on the left side.
Stained by Gram's method and Bismarck-brown. × 1000.

of the mouth, and does not invade even the subjacent tissues to any extent.

Association with other Organisms. — The diphtheria organism is sometimes present alone in the membrane, but more frequently associated with some of the pyogenic organisms, the streptococcus pyogenes being the organism most commonly present along with it. The staphylococci,

and occasionally the pneumococcus or the bacillus coli, may be present in some cases. Streptococci are often found lying side by side with the diphtheria bacilli in the membrane, and sometimes found penetrating more deeply into the tissues. In some cases of tracheal diphtheria, we have found streptococci alone, at a lower level in the trachea than the diphtheria bacilli, where the membrane was thinner and softer, the appearance in these cases being as if the streptococci acted as exciters of inflammation and prepared the way for the bacilli. It is still a matter of dispute as to whether the association of the diphtheria bacillus with the pyogenic organisms is a favourable sign or the contrary, nor is it certain what part they play locally in the disease. We know, however, that some of the complications of diphtheria may be due to their action. The extensive swelling of the tissues of the neck, sometimes attended by suppuration in the glands, and also various hæmorrhagic conditions, have been found to be associated with their presence, in fact, in some cases the diphtheritic lesion enables them to get a foothold in the tissues, where they exert their usual action and may lead to extensive suppurative change, or to septic poisoning. In cases where a gangrenous process is superadded, a great variety of organisms may be present, some of them being anærobic.

Against such complications anti-diphtheritic serum produces no favourable effect, as its action is specific and only neutralises the toxines of the diphtheria bacillus. In view of this fact, in some cases the anti-streptococcic serum has been used along with it, and it is apparent that in such conditions the bacteriological examination of the parts affected may afford valuable indications as to treatment.

Cultivation.—The diphtheria bacillus grows best in cultures at the temperature of the body; growth still takes place at 22° C., but ceases at 20° C. The best media are the following: Löffler's original medium,[1] solidified blood

[1] 3 parts calf's or lamb's blood serum, plus 1 part of ordinary peptone bouillon made from veal and containing, in addition, 1 per cent grape sugar. Inspissate as with ordinary serum.

serum, alkaline blood serum (Lorrain Smith), blood agar, and the ordinary agar media, though glycerine agar is less suitable than the others. If inoculations be made on the surface of blood serum with a piece of diphtheria membrane, colonies of the bacillus appear within twenty-four hours, and often before any other growths are visible. The colonies are small circular discs of opaque whitish colour, their centre being thicker and of darker greyish appearance when viewed by transmitted light than the periphery. On the second or third day they may reach 4 mm. in size, but when numerous they remain smaller. On the agar media the colonies

FIG. 83.—Colonies of the diphtheria bacillus on sloped agar, showing darker centres (with transmitted light). Two days' growth at 37° C. Natural size.

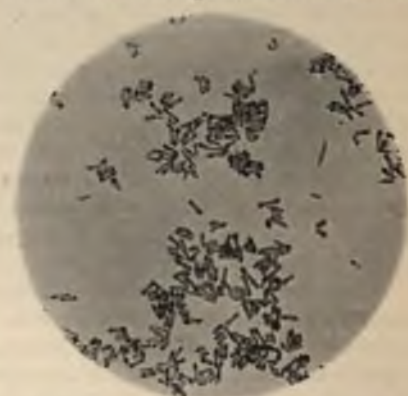

FIG. 84.—Diphtheria bacilli from a twenty-four hours' culture on agar. Stained with methylene-blue. × 1000.

have much the same appearance (Fig. 83) but grow less quickly, and sometimes they may be comparatively minute, so as rather to resemble those of the streptococcus pyogenes. In stroke cultures the growth forms a continuous layer of the same dull whitish colour, the margins of which often show single colonies partly or completely separated.

On *gelatine* at 22° C. a puncture culture shows a line of dots along the needle track, whilst at the surface a small disc forms, rather thicker in the middle. In none of the media does any liquefaction occur. In *bouillon* the organism produces a turbidity which soon settles to the bottom and forms a powdery layer on the wall of the vessel, the upper part of the fluid being left clear. The medium becomes acid during the first two or three days, and several days later again acquires an alkaline reaction.

In these media the bacilli show the same characters as in the membrane, but the irregularity in staining is more marked (Figs. 84, 85). They are at first fairly uniform in size and shape, but if a culture is examined from day to day it will be found that their appearance gradually becomes irregular. Many become swollen at their ends into club-shaped masses which are stained deeply, and the protoplasm becomes broken up into globules with unstained parts between (Fig. 86). Some become thicker throughout, and segmented so as to appear like large cocci, and others show globules at their ends, the rest of the rod appearing as a faintly-stained line. These are to be regarded as involution forms, and they occur more quickly and abundantly on the media less suitable for their growth, *e.g.*, more quickly on glycerine agar than on serum. The bacilli are quite devoid of motility, and they do not form spores.

FIG. 85.—Diphtheria bacilli of larger size than in previous figure, showing also irregular staining of protoplasm. From a three days' agar culture.
Stained with weak carbol-fuchsin. × 1000.

Staining.—They take up the basic aniline dyes, *e.g.*, methylene-blue in watery solution, with great readiness, and stain deeply. They also retain the colour in Gram's method.

Powers of Resistance, etc.—In cultures the bacilli possess long duration of life. Even when kept at 37° C. for one or two months they may be shown by subcultures to be still alive; at the room temperature they survive still longer. In the moist condition, whether in cultures or in membrane, they have a low power of resistance, being killed at 60° C. in a few minutes. On the other hand, in the dry condition they have great powers of endurance. In membrane which is perfectly dry, for example, they can resist a temperature of 98° C. for an hour. Dried diphtheria membrane, kept in the absence of light and at the room temperature, has been proved to contain diphtheria bacilli still living and virulent at the end of several months. The presence of light, moisture, or a higher temperature causes them to die out more rapidly. Corresponding results have been obtained with bacilli obtained from cultures and kept on dried threads. These facts, especially with regard to drying, are of great importance, as they show that the contagium of diphtheria may be preserved for a long time in the dried membrane. It follows, of course, that cultures can be readily obtained from membrane even after it has been dried.

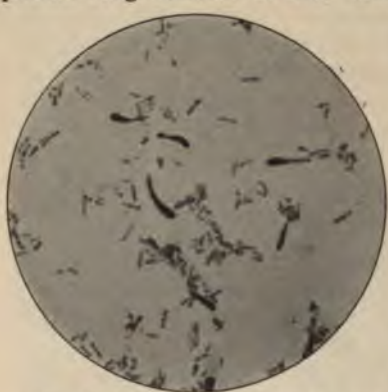

FIG. 86.—Involution forms of the diphtheria bacillus; from an agar culture of seven days' growth.
Stained with carbol-thionin-blue. × 1000.

Effects of Inoculation.—In considering the effects produced in animals by experimental inoculations of pure cultures, we have to keep in view the local changes which occur in diphtheria, and also the symptoms of general poisoning.

Löffler in his original paper stated that in the case of rabbits, guinea-pigs, pigeons, and fowls the bacilli taken from pure cultures produced no change on healthy mucous membranes, but when the latter were injured by scarification or otherwise the production of false membrane resulted. A similar result was obtained when the trachea was inoculated after tracheotomy had been performed. In this case the surrounding tissues became the seat of a blood-stained œdema, and the lymphatic glands were enlarged, the general picture resembling pretty closely that of laryngeal diphtheria. These results have been amply confirmed by other observers. The membrane produced by such experiments is usually less firm than in human diphtheria, and the bacilli are not generally found in such large numbers in the membrane. Rabbits inoculated after tracheotomy often die, and Roux and Yersin were the first to observe that in some cases paralysis similar to that produced by other methods to be described, may appear before death.

Subcutaneous injection in guinea-pigs, of diphtheria bacilli in a suitable dose, produces death within thirty-six hours. At the site of inoculation there is a small patch of greyish membrane, whilst in the tissues around there is extensive inflammatory œdema, often associated with hæmorrhages, and there is also some swelling of the corresponding lymphatic glands. The internal organs show general congestion, the suprarenal capsules being especially affected and often showing hæmorrhage. The renal epithelium may show cloudy swelling, and there is often effusion into the pleural cavities. After injection the bacilli increase in number for a few hours, but this multiplication soon ceases, and at the time of death they may be less numerous than when injected. The bacilli remain quite local,[1] cultures

[1] This may be stated as a general law, though in exceptional cases a few bacilli have been detected in internal organs.

made from the blood and internal organs giving negative results. If a non-fatal dose of a culture be injected, a local necrosis of the skin and subcutaneous tissue may follow at the site of inoculation.

In rabbits, after subcutaneous inoculation, results of the same nature follow, but these animals are less susceptible than guinea-pigs, and the dose requires to be proportionately larger. The dog and sheep are also susceptible to inoculation with virulent bacilli, but the mouse and rat enjoy a high degree of immunity. Klein found that cats also were susceptible to inoculation, the changes resulting being of a somewhat similar nature to those described. The animals usually die after a few days, and *post mortem* there is well-marked nephritis. He also found that after subcutaneous injection in cows, a vesicular eruption appeared on the teats of the udder, the fluid in which contained diphtheria bacilli. The animals gradually wasted and died after two to three weeks, the changes in the internal viscera being of the same nature as those in other animals. At the time of death the diphtheria bacilli were still alive and virulent at the site of injection. The striking fact in connection with these experiments is that the diphtheria bacilli passed into the circulation and were present in the eruption on the udder. He considers that this may throw light on certain epidemics of diphtheria in which the contagion was apparently carried by the milk.

Intraperitoneal injection of the bacilli in sufficient quantity in the guinea-pig produces death less rapidly than when the same dose is injected subcutaneously. The bacilli are chiefly confined to the peritoneum and gradually diminish in number.

Intravenous injection of virulent cultures in the rabbit often produces death within three days, there being symptoms of general poisoning with great prostration, and muscular feebleness. There may also be well-marked nephritis, but in such experiments Roux and Yersin found that the bacilli rapidly disappeared from the blood, and even after the injection of 1 c.c. of a broth culture no trace

of the organisms could be detected by culture after twenty-four hours.

In rabbits after injection into the trachea and also after subcutaneous injection, if the animals survive for some time, *paralytic symptoms* may appear, and in a few days gradually become more marked and lead to a fatal result, death sometimes not occurring till the end of the fifth week. This paralysis may also occur in dogs and other animals.

In all these experiments, with the exception of Klein's experiments on cows, the bacilli remained local. As the symptoms of poisoning and ultimately a fatal result occur when the bacilli are diminishing in number, or even after they have practically disappeared, Roux and Yersin inferred that the chief effects were produced by the products of the organisms, and this supposition they proved to be correct by a remarkable series of experiments with the filtered cultures.

The Toxines of Diphtheria.—Roux and Yersin found as above stated that a growth of virulent diphtheria bacilli in broth produced at first an acid reaction, which was followed later by a return to the alkaline condition. (Spronck, however, has shown that when the broth is quite free from glucose the acid reaction does not occur, and this is the case when the meat from which the broth is made is kept till traces of decomposition appear.) At the end of three or four weeks, the reaction being then markedly alkaline, the cultures freed from bacilli by filtration through a porcelain filter were found to be highly toxic. The filtrate when injected into guinea-pigs and other animals produces practically the same effects as the living bacilli, with the exception that locally there is no formation of false membrane; the internal organs show the same changes, and locally there is inflammatory œdema, which may be attended by a certain amount of necrotic change. The toxicity may be so great that .1 c.c. or even less may be fatal to a guinea-pig in twenty-four hours. In rabbits, when the dose is large, the intestines are found to be distended with fluid, and there may be diarrhœa; if the animals

survive for two or three days there is usually albuminuria, and *post mortem* nephritis is found to be present.

In the case of the toxine as of the living bacilli, when the animals such as guinea-pigs, rabbits, dogs, etc., survive long enough, paralytic phenomena may occur. The hind limbs are usually affected first, the paralysis afterwards extending to other parts, though sometimes the fore-limbs and neck first show the condition. After paralysis has appeared, a fatal result usually follows in the smaller animals, but in dogs recovery may take place. One point of much interest in relation to the relative nature of toxicity is the high degree of resistance to the toxine possessed by mice and rats. Roux and Yersin, for example, found that 2 c.c. of toxine, which was sufficient to kill a rabbit in sixty hours, had no effect on a mouse, whilst of this toxine even $\frac{1}{15}$ c.c. produced extensive necrosis of the skin of the guinea-pig.

Properties and Nature of the Toxine.—The toxic substance in filtered cultures is a relatively unstable body. When kept in sealed tubes in the absence of light, it preserves its powers almost unaltered for several months, but on the other hand, gradually loses them when exposed to the action of light and air. Heating at 58° C. for two hours destroys the toxic properties in great part, but not altogether. When, however, the toxine is evaporated to dryness, it has much greater resistance to heat. One striking fact, discovered by Roux and Yersin, is that after an organic acid, such as tartaric acid, is added to the toxine the toxic property disappears, but that it can be in great part restored by again making the fluid alkaline.

The toxic body in filtered cultures can be precipitated by alcohol, and is also carried down by calcium phosphate. It is, however, soluble in water and dialyses somewhat slowly through animal membranes. By repeated precipitation and again dissolving, aided by dialysis, a solution is obtained which, on evaporating to dryness, gives a whitish yellow powder containing the toxic body, though not in a chemically pure condition. From the characters described

Roux and Yersin considered that it belonged to the group of diastases or enzymes.

The true chemical nature of the diphtheria toxine is still unknown, and the matter is further complicated by the probability that a ferment formed by the bacilli produces other toxic bodies. Guinochet showed that toxine was also formed from the bacilli when grown in urine with no proteid bodies present. After growth had taken place he could not detect proteid bodies in the fluid, but on account of the very minute amount of toxine present, their absence could not be excluded. Uschinsky also found that toxic bodies were produced by diphtheria bacilli when grown in a proteid-free medium. It follows from this that if the true toxine is a proteid, it may be formed by synthesis within the bodies of the bacilli, and not by a change in the proteid of the culture fluid brought about by their action. Brieger and Boer have separated from diphtheria cultures a toxic body which gives no proteid reaction (*vide* p. 141).

Toxic bodies have also been obtained from the tissues of those who have died from diphtheria. Roux and Yersin, by using a filtered watery extract from the spleen from very virulent cases of diphtheria, produced in animals death after wasting and paralysis, and also obtained similar results by employing the urine. The subject of toxic bodies in the tissues, however, has been specially worked out by Sidney Martin. He has separated from the tissues and especially from the spleen of patients who have died from diphtheria, by precipitation by alcohol, chemical substances of two kinds, namely, albumoses (proto- and deutero-, but especially the latter), and an organic acid. The albumoses when injected into rabbits especially in repeated doses, produce fever, diarrhœa, paresis, and loss of weight, with ultimately a fatal result. As in the experiments with the toxine from cultures, the posterior limbs are first affected; afterwards the respiratory muscles, and finally the heart, are implicated. He further found that this paresis is due to well-marked changes in the nerves. The axis cylinders first become affected, breaking up into globules; ultimately the

medullary sheaths are involved, and may break across, so that degeneration occurs in the peripheral portion of the nerve fibres. Such changes occur irregularly in patches, both sensory and motor fibres being affected. Fatty change takes place in the associated muscle fibres. There may also be a similar condition in the cardiac muscle. The organic acid has a similar but weaker action. Substances obtained from diphtheritic membrane have an action like that of the bodies obtained from the spleen, but in higher degree. Martin considers that this is due to the presence in the membrane of an enzyme which has a proteolytic action within the body, resulting in the formation of poisonous albumoses. According to this view the actually toxic bodies are not the direct product of the bacillus, but are formed by the enzyme which is produced by it locally in the membrane. Cartwright Wood has also found that when diphtheria cultures in an albumin-containing medium are filtered germ-free and exposed to 65° C. for an hour (the supposed ferments being thus destroyed), there still remain albumoses which produce febrile reaction and are active in developing immunity. The existence of ferments, though highly probable, cannot, however, be considered to be yet completely proved. Nor is it certain whether the proteids obtained by precipitation from cultures and from the tissues are in themselves toxic, or whether the toxic bodies are carried down along with them.

Immunity.—This is described in the general chapter on immunity. It is sufficient to state here that a high degree of immunity, against both the bacilli and their toxines, can be produced in various animals by gradually increasing doses either of the bacilli or of their filtered toxines (*vide* Chap. XIX.).

Variations in the Virulence of the Diphtheria Bacillus.—In cultures on serum the diphtheria bacilli retain their virulence fairly well, but they lose it much more quickly on less suitable media, such as glycerine agar. Roux and Yersin in their experiments had some difficulty in attenuating the virulence; but they succeeded in doing so by grow-

ing the bacilli at an abnormally high temperature, namely 39·5° C., and in a current of air. By this method the virulence was so much diminished that the organisms became practically innocuous. When the virulence was much diminished, these observers found that it could be restored if the bacilli were inoculated into animals along with a culture of the streptococcus of erysipelas, inoculation of the bacilli alone not being successful for this purpose. If, however, the virulence had fallen very low, even the presence of the streptococci was insufficient to restore it. As a rule, the most virulent cultures are obtained from the gravest cases of diphtheria, though to this rule there are exceptions. It has been abundantly established that after the cure of the disease, the bacilli may persist in the mouth for two or three weeks, though they often quickly disappear. Roux and Yersin found by making cultures at various stages after the termination of the disease, that these bacilli in the mouth gradually become attenuated. These observations are of importance in relation to the subject of the pseudo-diphtheria bacillus. At present it would scarcely be safe to make a definite statement as regards the relation of virulence to the size of the bacilli. Perhaps the majority of observers have found that the bacilli of the larger form are usually more virulent than those of the shorter form; but this is not invariably the case, as sometimes short forms are obtained which possess an extremely virulent character. Both the long and the short forms may become attenuated in the same way.

The so-called Pseudo-diphtheria Bacillus.—Löffler, in 1887, was the first to describe a bacillus having closely the characters of the diphtheria bacillus, but differing from it in its want of virulence. To this organism he gives the name *pseudo-diphtheria bacillus*, and looked upon it as a distinct species. Hofmann, in 1888, published an account of his investigations on this subject. He obtained the pseudo-diphtheria bacillus from the throat in healthy conditions, and also in non-diphtheritic affections. His conclusions with regard to the distinct character of this

bacillus were similar to those of Löffler. Since that time the organism has been the subject of much research and discussion. Roux and Yersin, on the other side, have found that this bacillus corresponds in all its characters with a greatly attenuated diphtheria bacillus, and conclude that it is really of the same nature. They failed to make it virulent by any method; but this result was also obtained in the case of greatly attenuated diphtheria bacilli. There can be no doubt that a number of different organisms have been described under this name, some of which can be distinguished by their cultural and microscopical characters. In some cases the colonies are whiter, and more shining on the surface; in others the growth in broth never produces an acid reaction, and is more abundant and flocculent; and others, again, have not the same microscopical appearance in young cultures as the diphtheria bacillus. On the other hand, it is well established that there can be not infrequently cultivated from the throat in various conditions an organism which has all the characters of a diphtheria bacillus, with the single exception that it is not virulent to animals, and does not produce toxine. Biggs has found that there are two varieties of pseudo-diphtheria bacillus, one of which produces an acid reaction in broth containing glucose, whilst the other does not. According to his statistics the two varieties appear to occur with about the same frequency, and these observations have been in the main confirmed by Cobbett and Phillips. It is rare, however, that these pseudo-diphtheria bacilli occur in large numbers in the throat as found by microscopical examination and by cultures, and it is not often that difficulties in diagnosis arise. In some cases, however, such difficulty may be met with; and in the first place, all the cultural characters must be carefully examined, including the reaction produced in broth. By this procedure it may be determined whether a particular organism differs in certain points from the diphtheria organism. In cases where it corresponds in all these characters, distinction, if such exists, can be obtained by means of inoculations only. But we consider that for all

practical purposes an organism having all the microscopical and cultural characters of the diphtheria bacillus, may be accepted as such. Even if it is non-virulent, it is possibly only an attenuated diphtheria bacillus.

The question, however, has a special interest in regard to the *origin and spread of the disease.* As is well known, the disease usually spreads by infection, direct or indirect, from patient to patient; but sometimes it appears to start afresh, as it were. In the latter case the existence of the pseudo-diphtheria bacillus may afford an explanation of the occurrence. This bacillus is frequently found even in healthy subjects. For example, Roux and Yersin found it in the throats of twenty-six out of fifty-nine children examined, living in healthy surroundings. If, accordingly, it may become virulent under certain circumstances, this may explain the occurrence of fresh outbreaks. At present, however, we do not know definitely that such is the case, still less do we know conditions which render it virulent.

Diphtheria does not affect the lower animals, with the exception of cats, which have sometimes been observed to suffer from a similar disease, in association with human epidemics. Klein has found the diphtheria bacillus in the throat of cats in such circumstances. The so-called diphtheria of pigeons, calves, and other animals is produced by entirely different organisms.

The term xerosis bacillus has been given to an organism first observed by Kuschbert and Neisser in xerosis of the conjunctiva, and which has been since found in many other affections of the conjunctiva and even in normal conditions. Morphologically it is practically similar to the diphtheria bacillus, and even in cultures presents very minor differences. It is, however, non-virulent to animals, and, according to Eyre, does not produce an acid reaction in neutral bouillon; in this way it can be distinguished from the diphtheria bacillus.

Action of the Diphtheria Bacillus—Summary.—From a study of the morbid changes in diphtheria and of the results produced experimentally by the bacillus and its toxines, the following summary may be given of its action in

the body. Locally, the bacillus produces inflammatory change with fibrinous exudation, but at the same time cellular necrosis is also an outstanding feature. Though false membranes have not been produced by the toxines, a necrotic action may result when these are injected subcutaneously. The toxines also act upon the blood vessels, and hence œdema and tendency to hæmorrhage are produced. This action on the vessels is also exemplified by the general congestion of organs, and sometimes by the occurrence of hæmorrhages as in the suprarenal capsules. The hyaline change in the walls of arterioles and capillaries so often met with in diphtheria, is another example of the action of the toxine. The toxines have also a pernicious action on highly-developed cells and on nerve fibres. Thus in the kidney, cloudy swelling occurs, which may be followed by actual necrosis of the secreting cells, and along with these changes albuminuria is present. The action is also well seen in the case of the muscle fibres of the heart, which may undergo a sort of hyaline change followed by granular disintegration or by an actual fatty degeneration. These changes are of great importance in relation to heart failure in the disease. Changes of a somewhat similar nature have been recently observed in the nerve cells of the central nervous system, those lying near the capillaries, it is said, being affected first. But probably the most remarkable action is that on the peripheral nerves, which is shown first by the disintegration of the medullary sheaths as already described, and which is the essential change in most cases of post-diphtheritic paralyses.

Methods of Diagnosis.—The bacteriological diagnosis of diphtheria depends on the discovery of the bacillus. As the bacillus occurs in largest numbers in the membrane, a portion of this should be obtained whenever it is possible, and transferred to a sterile test-tube. (The tube can be readily sterilised by boiling some water in it.) If, however, membrane cannot be obtained, a scraping of the surface with a platinum loop may be sufficient. Where

the membrane is confined to the trachea the bacilli are often present in the secretions of the pharynx, and may be obtained from that situation by swabbing it with cotton wool (non-antiseptic) or by any other means convenient, the swab being put into a sterile tube or bottle for transport.

The means for identifying the bacillus are (*a*) *By microscopical examination.*—For microscopical examination it is sufficient to tease out a piece of the membrane with forceps and rub it on a cover-glass, or if it be somewhat dry a small drop of distilled water should be added. The films are then dried in the usual way and stained with any ordinary basic stain, though methylene-blue is on the whole to be preferred, used either as a saturated watery solution or in the form of Löffler's solution. After staining for two or three minutes the films are washed in water, dried, and mounted. As a rule no decolorising is necessary, as the blue does not overstain. Any secretion from the pharynx or other part is to be treated in the same way. The value of microscopical examination alone depends much upon the experience of the observer. In some cases the bacilli are present in characteristic form in such numbers as to leave no doubt in the matter. In other cases a few only may be found, mixed with large quantities of other organisms, and sometimes their characters are not sufficiently distinct to render a definite opinion possible. We have frequently obtained the bacillus by means of cultures, when the result of microscopical examination of the same piece of membrane was non-conclusive. As already said, however, microscopical examination alone is more reliable after the observer has had experience in examining cases of diphtheria and making cultures from them.

(*b*) *By making cultures.*—For this purpose a piece of the membrane should be separated by forceps from the pharynx or other part when that is possible. It should be then washed well in a tube containing sterile water, most of the surface impurities being removed in this way. A

fragment is then fixed in a platinum loop by means of sterile forceps, and a series of stroke cultures are made on the surface of any of the media mentioned, the same portion of the membrane being always brought into contact with the surface. The tubes are then placed in the incubator at 37° C., and, in the case of the serum media and blood-agar, the circular colonies of the diphtheria bacillus are visible in twenty-four hours. A small portion of a colony is then removed by means of a platinum needle, stained, and examined in the usual way, the characteristic appearance of the organism being readily recognised.

In cases where a suspicion arises that the organism found is the pseudo-diphtheria bacillus, a broth containing a trace of glucose should be inoculated and kept at the body temperature for two days. If the reaction remains alkaline the diphtheria bacillus may be excluded, but if it becomes acid the organism may still be the so-called pseudo-diphtheria bacillus. All the microscopical and cultural characters must then be carefully observed, and its degree of virulence may be ascertained by inoculating a guinea-pig, say with 1 c.c. of a broth culture of two days' growth. (See also pp. 345, 346.)

CHAPTER XVI.

TETANUS.[1]

SYNONYMS.—LOCKJAW. GERMAN, WUNDSTARRKRAMPF. FRENCH, TETANOS.

Introductory.—Tetanus is a disease which in natural conditions affects chiefly man and the horse. Clinically it is characterised by the gradual onset of general spasms of the voluntary muscles, commencing in those of the jaw and the back of the neck, and extending to all the muscles of the body. These spasms are of a tonic nature, and, as the disease advances, succeed each other with only a slight intermission of time. There are often, towards the end of a case, fever and rise of respiration and pulse-rate. The disease is usually associated with a wound received four to fourteen days previously, and which has been defiled by earth or dung. Such a wound may be very small. The disease is, in the majority of cases, fatal. *Post mortem* there is little to be observed. The most marked feature is the occurrence of patches of congestion in the spinal cord, and especially the medulla.

Historical.—To the pathologist the disease was, till re-

[1] This disease is not to be confused with the "tetany" of infants, which in its essential pathology probably differs from tetanus. This remark of course does not exclude the possibility of the occurrence of true tetanus in very young subjects.

cently, a complete mystery; for, while certain lesions were often met with, they were slight in extent, and no explanation whatever could be given of their occurrence. The general association of the condition with the presence of wounds, suggested that some infection took place through the latter, but nothing was known as to the nature of this infection. Carle and Rattone in 1884 announced that they had produced the disease in a number of animals by inoculation with material from a wound in tetanus. They thus demonstrated the transmissibility of the disease. An important paper by Nicolaier appeared in 1885. This author infected mice and rabbits with garden earth, and found that many of them developed tetanus. Suppuration occurred in the neighbourhood of the point of inoculation, and in this pus, besides other organisms, there was always present when tetanus had occurred, a bacillus having certain constant microscopic characters as regards size and staining reaction. Inoculation of fresh animals with such pus reproduced the disease. Nicolaier's attempts at its isolation by the ordinary gelatine plate culture method were, however, unsuccessful. He succeeded in getting it to grow in liquid blood serum, but always in mixture with other organisms. Infection of animals with such a culture produced the disease. These experiments were evidently incomplete, but were confirmed by Rosenbach, who produced the disease in animals by inoculation, and noted the presence of the same bacillus. Though he failed to obtain it in pure culture, he cultivated the other organisms present, and inoculated them with negative results. He further pointed out, as characteristic of the bacillus, its development of terminal spores. In 1889, Kitasato succeeded in isolating from the local suppuration of mice inoculated from a human case, several bacilli, only one of which, when injected in pure culture into animals, caused the disease, and which was now named the B. tetani. This organism is the same as that observed by Nicolaier and Rosenbach. Kitasato found that the cause of earlier culture failures was the fact that it could only grow in the absence of oxygen. The

pathology of the disease was further elucidated by Brieger and Fraenkel, and still more satisfactorily by Faber, who, having isolated bacterium-free poisons from cultures, reproduced the symptoms of the disease.

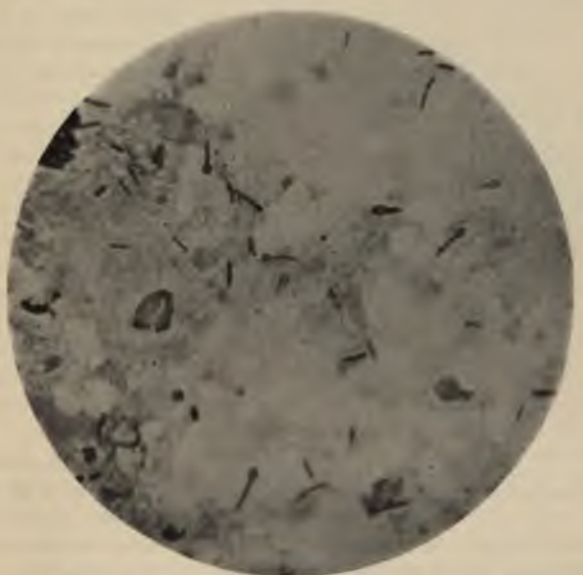

FIG. 87.—Film preparation of discharge from wound in a case of tetanus, showing several tetanus bacilli of "drumstick" form. (The thicker bacillus with oval and not quite terminal spore, in the upper part of the field towards the right side, is not a tetanus bacillus but a putrefactive anærobe which was obtained in pure culture from the wound.)
Stained with gentian-violet. × 1000.

Bacillus Tetani.—If in a case of tetanus naturally arising in man, there be a definite wound with pus formation or necrotic change, the bacillus tetani may be recognised in film preparations from the pus, if the characteristic spore formation has occurred. If, however, the tetanus bacilli have not formed spores, they appear as somewhat

slender rods, without presenting any characteristic features. There is usually present in such pus a great variety of other organisms—cocci and bacilli. The characters of the bacillus are, therefore, best studied in cultures. It is then seen to be a slender organism, usually about 4 μ to 5 μ in length and .4 μ in thickness, with somewhat rounded ends. It occurs singly or in threads, the latter being more common in fluid media. It stains readily by any of the usual stains and also by Gram's method. A feature in it is the uniformity with which the protoplasm stains. It is very slightly motile, and its motility can be best studied in a hanging-drop preparation kept on a warm stage. When stained by the special methods already described, it is found to possess flagella of considerable length, either at both ends or all round (Kanthack). At incubation temperature it readily forms spores, and then presents a very characteristic appearance. The spores are round, and in diameter may be three or four times the thickness of the bacilli. They are developed at one end of a bacillus, which thus assumes what is usually described as the drumstick form (Figs. 87, 88). In a specimen stained with a watery solution of gentian-violet or methylene-blue, the spores are uncoloured except at the periphery, so that the appearance of a small ring is produced; if a powerful stain such as carbol-fuchsin be applied for some time, the spores become deeply coloured like the bacilli. Further, they may become

FIG. 88.—Tetanus bacilli; some of which possess spores. From a culture in glucose agar, incubated for three days at 37° C. Stained with carbol-fuchsin. × 1000.

free in the culture medium. They can be stained by the appropriate methods.

Isolation.—The isolation of the tetanus bacillus is somewhat difficult. By inoculation experiments in animals, its natural habitat has been proved to be garden soil, and especially the contents of dung-heaps. From such sources, and from the pus of wounds in tetanus, it has been isolated by means of the methods appropriate for anærobic bacteria. It probably leads a saprophytic existence, but its function as a saprophyte is unknown. Often, however, instead of soil, etc., being taken as the original material, there is employed the pus locally developed in animals dead of the disease after inoculation with garden earth, etc. The best methods for dealing with such pus or with that derived from wounds in the natural disease are as follows :—

(1) The principle is to take advantage of the resistance of the spores of the bacillus to heat. A sloped tube of inspissated serum or a deep tube of glucose agar is inoculated with the pus and incubated at 37° C. for forty-eight hours, at the end of which time numerous spore-bearing bacilli can often be observed microscopically. The culture is then kept at 80° C. for from three-quarters to one hour, with the view of killing all organisms except those which have spored. A loopful is then added to glucose gelatine, and roll-tube cultures are made in the usual way and kept in an atmosphere of hydrogen at 22° C.; after five days the plates are ready for examination. Kitasato compares the colonies in gelatine plates to those of the B. subtilis. They consist of a thick centre with shoots radiating out on all sides. They liquefy the gelatine more slowly than the B. subtilis. This method of isolation is not always successful, partly because along with the tetanus bacilli, both in its natural habitats outside the body and in the pus of wounds, other spore-forming obligatory and facultative anærobes occur, which grow faster than the tetanus bacillus, and thus overgrow it.

(2) If in any discharge the spore-bearing tetanus bacilli be seen on microscopic examination, then a method of

isolation based on the same principle as the last may be adopted. Inoculations with the suspected material are made in half a dozen deep tubes of glucose agar, previously melted and kept at a temperature of 100° C. After inoculation they are again placed in boiling water and kept for varying times, say for half a minute, for one, three, four, five, and six minutes, respectively. They are then plunged in cold water till cool, and thereafter placed in the incubator at 37° C., in the hope that in one or other of the tubes all the organisms present will have been killed, except the tetanus spores which can develop in pure culture. Another variation may be adopted by making use of Vignal's method (p. 66) at any stage of the procedure just described. The isolation of the tetanus bacillus is in many cases a difficult matter, and various expedients require to be tried.

FIG. 89. — Stab culture of the tetanus bacillus in glucose gelatine, showing the lateral shoots (Kitasato). Natural size.

Characters of Cultures.—Pure cultures having been obtained, sub-cultures can be made in deep upright glucose gelatine or agar tubes. On *glucose gelatine* in such a tube there commences, an inch or so below the surface, a growth consisting of fine straight threads, rather longer in the lower than in the upper parts of the tube, radiating out from the needle track (Fig. 89). Slow liquefaction of the gelatine takes place, with slight gas formation. In *agar* the growth is not characteristic, consisting of small nodules along the needle track, with irregular short off-shoots passing out into the medium. There is slight formation of gas and, of course, no liquefaction. Growth also occurs in *blood serum* and also in *glucose bouillon* under anærobic conditions. The latter is the medium usually employed for

obtaining the soluble products of the organism. There is in it at first a slight turbidity, and later a thin layer of a powdery deposit on the walls of the vessel. All the cultures give out a peculiar burnt odour of rather unpleasant character.

Conditions of Growth, etc.—The B. tetani grows best at 37° C. The minimum growth temperature is about 14° C., and below 22° C. growth takes place very slowly. Growth takes place only in the absence of oxygen, the organism being a strict *anærobe*. Sporulation occurs at the end of twenty-four hours in cultures grown at 37° C.—much later at lower temperatures. Like other spores, those of tetanus are extremely resistant. They can usually resist boiling for five minutes, and can be kept in a dry condition for many months without being killed or losing their virulence. They have also high powers of resistance to antiseptics.

Pathogenic Effects.—The proof that the B. tetani is the cause of tetanus is complete. It can be isolated in pure culture, and when reinjected in pure culture it reproduces the disease. It may be impossible to isolate it from some cases of the disease, but we shall see reason for believing that the cause of this very probably is the small numbers in which it sometimes occurs.

(*a*) *The Disease as arising naturally.*—The disease occurs naturally, chiefly in horses and in man. Other animals may, however, be affected. There is usually some wound, often of a ragged character, which has either been made by an object soiled with earth or dung, or which has become contaminated with these substances. Suppuration very usually has occurred. On examination, the wound is usually found to consist of an irregular cavity with ragged walls, and microscopic sections show this cavity to be often surrounded by an area of necrosed tissue in which the tetanus bacilli may be very numerous. From the pus the ordinary pyogenic organisms can be isolated. If such pus be examined microscopically, bacilli resembling the tetanus bacillus may be recognised. If these have spored, there

can be practically no doubt as to their identity, as the drumstick appearance which the terminal spore gives to the bacillus is not common among other bacilli. Care must be taken, however, to distinguish it from other thicker bacilli with oval spores placed at a short distance from their extremities, such forms being common in earth, etc., and also met with in contaminated wounds (Fig. 87). It is important to note that the wound through which infection has taken place may be very small, in fact, may consist of a mere abrasion. In some cases, especially in the tropics, it may be merely the bite of an insect. The absence of a definite channel of infection has given rise to the term "idiopathic" tetanus. There is, however, practically no doubt that all such cases are true cases of tetanus, and that in all of them the cause is the B. tetani. The latter has also been found in the bronchial mucous membrane in some cases of the so-called rheumatic tetanus, the cause of which is usually said to be cold.

The pathological changes found *post mortem* are not striking. There may be hæmorrhages in the muscles which have been the subject of the spasms. These are probably due to mechanical causes. Naturally it is in the nervous system that we look for the most important lesions. In the spinal cord and medulla there is ordinarily a general redness of the grey matter, and the most striking feature is the occurrence of irregular patches of congestion which are not limited particularly to grey or white matter, or to any tract of the latter. These patches are usually best marked in the grey matter of the medulla and pons. There is general slight congestion, and some tendency to the same appearance of patches in the cerebrum and cerebellum, but to a much less extent than lower down. Microscopically there is little of a definite nature to be found. There is congestion, and there may be minute hæmorrhages in the areas noted by the naked eye. The ganglion cells may show appearances which have been regarded as degenerative in nature, and similar changes have been described in the white matter. The only marked feature is thus a vascular

disturbance in the central nervous system, with a possible tendency to degeneration in its specialised cells. The latter change may either be a consequence of the former, or both may be due to a common cause. While such appearances are often seen in the nervous system, cases occur where they are not at all well marked, or where they may be altogether absent. In the other organs of the body there are no constant changes.

We have said that the general distribution of pathogenic bacteria throughout the body is probably a relative phenomenon, and that bacteria usually found locally may occur generally and *vice versâ*. With regard to the tetanus bacillus it is, however, probably the case that very rarely, if ever, are the organisms found anywhere except in the local lesion.

(*b*) *The artificially-produced Disease.*—The disease can be communicated to animals by any of the usual methods of inoculation, but does not arise in animals fed with bacilli whether the latter contain spores or not. Kitasato found that pure cultures, injected subcutaneously or intravenously, caused death in mice, rats, guinea-pigs, and rabbits. In mice, symptoms appear in a day, and death occurs in two or three days, after inoculation with a loopful of a bouillon culture. The other animals mentioned require larger doses, and death does not occur so rapidly. The symptoms generally are those of the natural disease, the spasms beginning in the muscles nearest the site of inoculation. After death there is found slight hyperæmia without pus formation, at the seat of inoculation. The bacilli diminish in number, and may be absent at the time of death. The organs generally show little change.

Kitasato acknowledges that in these earlier experiments the quantity of culture medium injected along with the bacilli, already contained enough of the poisonous bodies secreted by the bacilli to cause death. The symptoms came on sooner than by the improved method mentioned below, and were, therefore, due to an intoxication with the toxines present, not to the inoculation with the bacilli. In

his subsequent work, therefore, he employed splinters of wood soaked in cultures in which spores were present, and subsequently subjected for one hour to a temperature of 80° C. The latter treatment not only killed all the bacilli, but, as we shall see, was sufficient to destroy the activity of the toxines. When such splinters are introduced subcutaneously, death results by the development of the spores which they carry. In this way he completed the proof that the bacilli by themselves can form toxines in the body and produce the disease.

The species of animals mentioned may also be inoculated with the pus of wounds which contain the tetanus bacilli. Further, if a small quantity of garden earth be placed under the skin of a mouse, death from tetanus takes place in a great many cases. Sometimes, however, in such circumstances death occurs without tetanic symptoms, and is not due to the tetanus bacillus but to the bacillus of malignant œdema, which also is of common occurrence in the soil (*v. infra*). By such experiments, supplemented by the culture experiments mentioned, the natural habitats of the B. tetani, as given above, have become known.

The Toxines of the Tetanus Bacillus.—The tetanus bacillus being thus accepted as the cause of the disease, we have to consider how it produces its pathogenic effects.

Almost contemporaneously with the work on diphtheria was the attempt made with regard to tetanus to explain the general symptoms produced, by supposing that the bacillus could excrete soluble poisons. It was first of all stated that ptomaines occurred in tetanus cultures and organs. Brieger, for instance, in his earlier work recorded that a base tetanin could be isolated from dead cultures, and this, as well as another base called tetanotoxin, was also obtained by Kitasato and Weyl. When injected into animals, these substances produced spasms and death, but though they may have contained the real toxine they were obtained by the earlier faulty methods.

In 1890 Brieger and Fraenkel announced that they had isolated a *toxalbumin* from tetanus cultures, and this body was independently discovered by Faber in the same year. Brieger and Fraenkel's body consisted practically of an

alcoholic precipitate from filtered culture in bouillon, and was undoubtedly toxic. The toxic properties of bacterium-free filtrates of pure cultures of the B. tetani were investigated in 1891 by Kitasato. He found that when the filtrate, in certain doses, was injected subcutaneously or intravenously into mice, tetanic spasms developed, first in muscles contiguous to the site of inoculation and later all over the body. Death resulted. He found that guinea-pigs were more susceptible than mice, and rabbits less so. No effect followed if the toxine were given in the animal's food. It is destroyed by the hydrochloric acid of the stomach. In order that a strongly toxic bouillon be produced, it must originally have been either neutral or slightly alkaline. Kitasato further found that the toxine was easily injured by heat. Exposure for a few minutes at 65° C. destroyed it. It was also destroyed by twenty minutes' exposure at 60° C. and by one and a half hours' at 55° C. Drying had no effect. It was, however, destroyed by various chemicals such as pyrogallol and also by sunlight. Behring has more recently pointed out that after the filtration of cultures containing toxine, the latter may very rapidly lose its power, and in a few days may only possess $\frac{1}{100}$th of its original toxicity. This he attributes to such factors as temperature and light, and especially to the action of oxygen.

Various attempts have been made to find out the nature of this toxine. Sidney Martin derived from the organs of persons dead of tetanus two classes of bodies. One of these consisted of a purified alcoholic precipitate (formed chiefly of albumoses). To these he attributes a fever-producing action. The other bodies were those soluble in alcohol and also in ether. They were non-proteid, and to them he attributed the excitation of the muscular spasms in tetanus. Uschinsky, moreover, has found that the bacillus can produce its toxine when growing in a fluid containing no proteid matter. The toxine may thus result from a metabolic action on the part of the bacillus, and not from the breaking up of the albumins on which it is living, though it no doubt has a digestive action on albumin. Brieger also has now

apparently come to the conclusion that the toxicity of the toxalbumins originally described by him is due to the presence of a non-proteid body. In his latest paper he describes the isolation, by a special method, of a toxine which is neither peptone, albumin, nor albuminate, and the nature of which is quite unknown.

Probably a *diastase* is concerned in the toxic action of the tetanus bacillus. Like a ferment, the toxine is destroyed, as we have seen, by comparatively low temperatures, but it may simply be an unstable chemical compound, for albuminous bodies not diastatic in nature may be changed at similar temperatures. The liquefaction (*i.e.*, probable peptonisation) of gelatine cultures advances *pari passu* with the development of toxines, and filtered bacterium-free cultures will still liquefy gelatine. It may be, however, that there is developed, in addition, a peptic ferment which will, of course, also pass through the filter. For if equal portions of the filtered culture be left in contact with equal portions of gelatine for various lengths of time, there is no increase of toxicity in those kept longest. There is thus no fresh development of toxine during the advancing liquefaction of the gelatine. Thus peptic digestion and toxine formations may be due to different vital processes on the part of the tetanus bacillus.

The strongest argument in favour of a ferment being concerned in the toxine production, is derived from the occurrence of a definite incubation period between the introduction of the toxine into an animal's body and the appearance of symptoms. This incubation period varies according to the species of animal employed, and the path of infection. In the guinea-pig it is from thirteen to eighteen hours, in the horse five days, and the incubation is shorter when the poison is introduced into a vein than when injected subcutaneously. Further, a dog can receive 300 c.c. of a culture of which the fatal dose for a guinea-pig is infinitesimal, without the incubation period being shortened. Certain remarkable results have been obtained by Courmont

and Doyon. A dog received a certain dose of toxine, and after tetanic symptoms had arisen, direct transfusion of its blood was practised, one of its arteries being connected with an artery in a healthy dog. In a few minutes the latter showed, according to the authors, tetanic symptoms. The interpretation to be put on this experiment would appear to be that what is called the tetanus toxine is not the real poisonous agent, but that when introduced into an animal's body it gives rise to chemical changes which result in the true toxine being formed. This looks like a fermentative action. Further, from the muscles of a tetanic dog Courmont and Doyon prepared an extract which had the effect of producing immediate tetanic spasms in a healthy animal, and which, unlike the tetanus toxine, was not destroyed by boiling. Careful control experiments showed that this body did not exist in the muscles of normal dogs, and that it was not the result of the tetanic spasms occurring in the muscle of the tetanic dog. They further found that tetanus toxine had no effect on a hibernating frog, but that if the animal had its temperature raised to from 30° to 34° C., tetanic symptoms appeared after an incubation period. The interpretation they put on this experiment is that at the lower temperature the toxine cannot act, while at the higher it can, and this, again, is what we should expect if it were a ferment. There is thus ground for suspecting that the tetanus toxine (*i.e.*, the filtrate of a tetanus culture) contains a ferment which in the animal tissues produces other toxic bodies.

With regard to its *physiological action*, it has been shown that the toxine has no effect on the sensory or motor endings of the nerves, but acts solely as an exciter of the reflex excitability of the motor cells in the spinal cord. The motor cells in the pons and medulla are also affected, and to a much greater degree than those in the cerebral cortex.

Whatever the nature of the toxine is, it is undoubtedly one of the most powerful poisons known. Even with his probably impure toxalbumin Brieger found that the fatal dose for a mouse was .0005 of a milligram. If

the susceptibility of man be the same as that of a mouse, the fatal dose for him would be .23 of a milligram or about $\frac{7}{2000}$ths of a grain.

There is one question which must arise in connection with tetanus, namely: Granted that the B. tetani is so widely present in the soil, how is it that the disease is not more common than it is, for wounds must constantly be contaminated with such soil? Experiments by Vaillard throw light on this point. We have seen that unless suitable precautions are adopted, in experimental tetanus in animals death results not from inoculation but from an intoxication with toxine previously existent in the fluid in which the bacilli have been growing. According to Vaillard, if spores rendered toxine-free, by being kept for a sufficient time at 80° C., are injected into an animal, death does not take place. It was found, however, that such spores can be rendered pathogenic by injecting along with them such chemicals as lactic acid, by injuring the point of inoculation so as to cause effusion of blood, by fracturing an adjacent bone, by introducing a mechanical irritant such as soil or a splinter of wood (as in Kitasato's experiments), or by the simultaneous injection of other bacteria such as the *staphylococcus pyogenes aureus*. These facts, especially the last, throw great light on the disease as it occurs naturally, for tetanus results especially from wounds which have been accidentally subjected to conditions such as those enumerated. Kitasato now holds that in the natural infection in man, the presence of tetanus spores along with foreign material such as splinters of wood or other bacteria, is necessary. Spores alone or tetanus bacilli without spores die in the tissues, and tetanus does not result.

Summary.—In view of all the facts available we must thus look on tetanus as caused by the B. tetani. The bacillus gains entrance to the body through wounds or abrasions, and, multiplying locally, produces poisons which diffuse into the tissues and have an elective action as stimulants of especially the spinal cord, but the chemical composition of which is not yet fully known. The enormous

potency of such poisons explains how, even in a fatal case, extreme smallness of the wound and difficulty in isolating the bacillus do not detract from the theory that the latter is the cause of the disease.

Immunity against Tetanus.—Antitetanic Serum.—The artificial immunisation of animals against tetanus has received much attention. The most complete study of the question is found in the work of Behring and Kitasato in Germany, and of Tizzoni and Cattani in Italy. The former observers found that such an immunity could be conferred by the injection of very small and progressively increasing doses of the tetanus toxine. The degree of immunity attained, however, was not high. More successful was the method of accompanying the early injections of such toxine with the subcutaneous introduction of small doses of iodine terchloride. Tizzoni and Cattani have also used the method of administering progressively increasing doses of living cultures attenuated in various ways, *e.g.*, by heat. By any of these methods susceptible animals can rapidly acquire great immunity, not only against many times the fatal dose of tetanus toxine, but also against injections of the living bacilli. The degree of immunisation acquired by an animal remains in existence for several months. Not only so, but the injection of the serum of such immune animals can protect susceptible animals against the subsequent infection with a fatal dose of tetanus bacilli or toxine. Further, if injected subsequently to such infection, the serum can prevent a fatal result, even when symptoms have begun to appear. The degree of success attained depends, however, on the shortness of the time which has elapsed between the infection with the bacilli or toxine and the injection of the serum. The longer the interval which is allowed to elapse, not only the greater must be the dose of the serum but the less likely is cure to occur. In animals, where symptoms have fully manifested themselves only a small proportion of cases can be saved. As in other cases, there is no evidence that the antitetanic serum has any detrimental effect on the bacilli. It only

neutralises the effects of the toxine. The standardisation of the antitetanic serum is of the highest importance. Behring recommends that for protecting animals a serum should be obtained of which one gram will protect 1,000,000 grams weight of mice against the minimum fatal dose of the bacillus or toxine. A mouse weighing twenty grams would thus require .00002 grams of such a serum to protect it against the minimum lethal dose. In the injection of such a serum subsequent to infection, if symptoms have begun to appear, 1000 times this dose would be necessary; a few hours later 10,000 times, and so on.

As the result of his experiments, Behring aimed at obtaining a curative effect in the natural disease occurring in man. For this purpose, as for his later laboratory experiments, he obtained serum by the immunisation of such large animals as the horse, the sheep, and the goat. The principles of the process were the same as in his earlier work, namely, the injection of toxine, accompanied at first with the injection of iodine terchloride. It was found that the greater the degree of the natural susceptibility of an animal to tetanus, the easier was it to obtain a serum of a high antitetanic potency. The horse was, therefore, the most suitable animal. If now we take for granted that the relative susceptibility of man and the mouse towards tetanus are nearly equal, a man weighing 100 kilograms would require .1 gram of the serum mentioned above, to protect him from inoculation with the minimum lethal dose of bacilli or toxine. If symptoms had begun to appear, 100 c.c. at once would be necessary, and as the injection of such a quantity might be inconvenient, Behring recommended that for man a more powerful serum should be obtained, viz. a serum of which one gram would protect 100,000,000 grams weight of mice.[1] Here, as in all antitetanic sera, the potency is maintained for several months if precautions are taken to avoid putrefaction. To this end

[1] The antitetanic serum sent out by the Pasteur Institute in Paris has a strength of 1 : 1,000,000,000. Of this it is recommended that 50 to 100 c.c. should be injected in one or two doses.

.5 per cent carbolic acid is usually added. In a case of tetanus in man, 100 c.c. of such a serum should be injected within twenty-four hours in five doses, each at a different part of the body, and this followed up by further injections if no improvement takes place.

Many cases of human tetanus have been thus treated, but with only a small measure of success. The improvement in the death-rate has not been nearly so marked as that which has occurred in diphtheria under similar circumstances. As in the case of diphtheria, however, the results would probably be better if more attention were paid to the dosage of the serum. We have seen that in mice, when once tetanic symptoms have appeared, the chance of saving a case is diminished, and the same is doubtless true of man. The great difficulty is that, as a matter of fact, we have not the opportunity of recognising the presence of the tetanus bacilli till they have begun to manifest their gravest effects. In diphtheria we have a well-marked clinical feature which draws attention to the probable presence of the bacilli—a presence which can be readily proved,—and the curative agent can be applied before the microbes have advanced far in their pathogenic course. In tetanus, the wound in which the bacilli exist may be, as we have seen, of the most trifling character, and even when a well-marked wound exists, the search for the bacilli is a matter of difficulty. Still, it might be well, when practicable, that every ragged, unhealthy-looking wound, especially when contaminated with soil, should, as a matter of routine, be examined bacteriologically. In such cases, undoubtedly, from time to time cases of tetanus would be detected early, and their treatment could be undertaken with more hope of success than at present. However, in the existing state of matters, whenever the first symptoms of tetanus appear, large doses, such as those above indicated, of a serum whose strength is known, should be at once administered. In giving a prognosis as to the probable result, the two clinical observations on which, according to Behring, chief reliance ought to be placed, are the presence or absence of interference with respiration, and the

rapidity with which the groups of muscles usually affected are attacked. If dyspnœa or irregularity in respiration comes on soon, and if group after group of muscles are quickly involved, then the outlook is extremely grave.

Of the nature of the antitoxine of tetanus we know little. It is not affected by heat, light, or atmospheric conditions. Brieger and Boer state that they have isolated it from the serum by the methods used to obtain the toxine.

Methods of Examination in a case of Tetanus.—The routine bacteriological procedure in a case presenting the clinical features of tetanus ought to be as follows:—

(*a*) *Microscopic.*—Though tetanus is not a disease in which the discovery of the bacilli is easy, still microscopic examination should be undertaken in every case. From every wound or abrasion from which sufficient discharge can be obtained, film preparations ought to be made and stained with any of the ordinary combinations, *e.g.*, carbol-fuchsin diluted with five parts of water. Drumstick-shaped spore-bearing bacilli are to be looked for. The presence of such, having characters corresponding to those of the tetanus bacilli, though not absolutely conclusive proof of identification, is yet sufficient for all practical purposes. If only bacilli without spores, resembling the tetanus bacilli, are seen, then the identification can only be provisional.

The microscopic examination of wounds contaminated by soil, etc., may, as we have said in some cases, lead to the anticipation that tetanus will probably result.

(*b*) *Cultivation.*—The methods to be employed in isolating the tetanus bacilli have already been described (p. 355). It may be added, however, that if the characteristic forms are not seen on microscopic examination of the material from the wound, they may often be found by inoculating a deep tube of one of the glucose media with such material, and incubating for forty-eight hours at 37° C. At the end of this period, spore-bearing tetanus bacilli may be detected microscopically, though of course mixed with other organisms.

(*c*) *Inoculation.*—Mice and guinea-pigs are the most

suitable animals. Inoculation with the material from a wound should be made subcutaneously. A loopful of the discharge introduced at the root of the tail in a mouse will soon give rise to the characteristic symptoms, if tetanus bacilli are present.

Malignant Œdema (*Septicémie de Pasteur*).

The organism now usually known as the bacillus of malignant œdema is the same as that first discovered by Pasteur and named *vibrion septique*. He described its characters, distinguishing it from the anthrax bacillus which it somewhat resembles morphologically, and also the lesions produced by it. He found that it grew only in anærobic conditions, but was able to cultivate it merely in an impure state. It was more fully studied by Koch, who called it the bacillus of malignant œdema, and pointed out that the disease produced by it is not really of the nature of a septicæmia, as immediately after death the blood is practically free from the bacilli.

In the human subject "malignant œdema" occurs as a spreading inflammatory œdema attended with emphysema, and ultimately followed by gangrene of the skin and subjacent parts. In many cases of this nature the bacillus of malignant œdema is present, associated with other organisms which aid its spread, but it is to be noted that a spreading gangrenous emphysema may be produced by other organisms than the bacillus of malignant œdema.

This bacillus has a very widespread distribution in nature, being present in garden soil, dung, and various putrefying animal fluids; and it is by contamination of lacerated wounds by such substances that the disease is usually set up in the human subject. Malignant œdema can be readily produced by inoculating susceptible animals, such as guinea-pigs, with garden soil. The bacillus is also often present in the intestine of man and animals, and has been described as being present in some gangrenous

conditions originating in connection with the intestine in the human subject.

Microscopical Characters.—The bacillus of malignant œdema is a comparatively large organism, being slightly less than 1 μ in thickness, that is, thinner than the anthrax bacillus. It occurs in the form of single rods 3 μ to 10 μ in length, but both in the tissues and in cultures in fluids it frequently grows out into long filaments, which may be uniform throughout or segmented at irregular intervals. In cultures on solid media it chiefly occurs in the form of shorter rods with somewhat rounded ends. The rods are motile, possessing several laterally placed flagella, but in a given specimen, as a rule, only a few bacilli show active movement. Under suitable conditions they form spores which are seen about the centre of the rods and have an oval shape, their thickness somewhat exceeding that of the bacillus, so that they project slightly (Fig. 90). The bacillus can be readily stained by any of the basic aniline stains, but loses the colour in Gram's method, in this way differing from the anthrax bacillus.

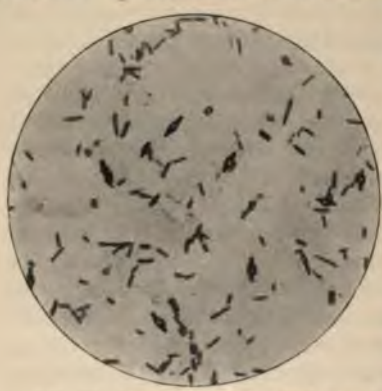

FIG. 90.—Bacillus of malignant œdema, showing spores. From a culture in glucose agar, incubated for three days at 37° C. Stained with weak carbol-fuchsin. × 1000.

Characters of Cultures.—This organism grows readily at ordinary temperature, but only under *anærobic* conditions. In a puncture culture in a deep tube of glucose gelatine, the growth appears as a whitish line giving off minute short processes, the growth, of course, not reaching the surface of the medium. Soon liquefaction occurs, and a long fluid funnel is formed, with turbid contents and flocculent masses

of growth at the bottom. At the same time bubbles of gas are given off, which may split up the gelatine. The colonies in gelatine plates under anærobic conditions appear first as small whitish points which under the microscope show a radiating appearance at the periphery, resembling the colonies of the bacillus subtilis. Soon, however, a sphere of liquefaction occurs in which the growth forms an irregular mass, though a narrow zone with radiate striation may sometimes be seen at the margin of the sphere; gas is developed around the colonies.

In deep tubes of glucose agar at 37° C., growth is extremely rapid. Along the line of puncture, growth appears as a somewhat broad white line with lateral projections here and there. The medium is quickly cracked in various directions by the evolution of gas, and may be pushed upwards so high as to displace the cotton-wool plug. The cultures possess a peculiar heavy, though not putrid, odour.

Spore formation occurs above 20° C., and is usually well seen within forty-eight hours at 37° C. The spores have the usual high powers of resistance, and may be kept for months in the dried condition without being killed.

Experimental Inoculation.—A considerable number of animals—the guinea-pig, rabbit, sheep, and goat, for example—are susceptible to inoculation with this organism. The ox is said to be quite immune to experimental inoculation, though it can, under certain conditions, contract the disease by natural channels. The guinea-pig is the animal most convenient for experimental inoculation. When the disease is set up in the guinea-pig by subcutaneous inoculation with garden soil, death usually occurs in about twenty-four to forty-eight hours. There is an intense inflammatory œdema from the site of inoculation, which extends over the wall of the abdomen and thorax. The skin and subcutaneous tissue are infiltrated with a reddish-brown fluid and softened; they contain bubbles of gas and are at places gangrenous. The superficial muscles are also involved. These parts have a very putrid odour. The internal

organs are congested, the spleen soft but not much enlarged. In such conditions the bacillus of malignant œdema, both in short and long forms, will be found in the affected tissues along with various other organisms. Spores may be present, especially when the examination is made some time after the death of the animal. If the animal is examined immediately after death, a few of the bacilli may be present in the peritoneum and pleuræ, usually in the form of long motile filaments, but they are almost invariably absent from the blood. A short time after death, however, they spread directly into the blood and various organs, and may then be found in considerable numbers.

Subcutaneous inoculation with pure cultures of the bacillus of malignant œdema produces chiefly a spreading bloody œdema, the muscles presenting a bright-red colour; but there is little formation of gas, and the putrid odour is almost absent.

When the bacilli are injected into mice, however, they enter and multiply in the blood stream, and they are found in considerable numbers in the various organs, so that a condition not unlike that of anthrax is found. The spleen also is much swollen.

The virulence of the bacillus of malignant œdema varies considerably in different cases, and it always becomes diminished in cultures grown for some time. To produce a fatal disease, a relatively large number of the organisms is necessary, and these must be introduced deeply into the tissues, inoculation by scarification being followed by no result. A smaller dose produces a fatal result when injected along with various other organisms (bacillus prodigiosus, etc.).

Immunity.—Malignant œdema was one of the first diseases against which immunity was produced by injection of toxines. The filtered cultures of the bacillus in sufficient doses produce death with the same symptoms as those caused by the living organisms, but a relatively large quantity is necessary. Chamberland and Roux (1887) found that if guinea-pigs were injected with several

non-fatal doses of cultures sterilised by heat or freed from the bacilli by filtration, immunity against the living organism could be developed in a comparatively short time. They found that the filtered serum of animals dead of the disease is more highly toxic, and also gives immunity when injected in small doses. These experiments have been confirmed by Sanfelice.

Methods of Diagnosis.—In a case of supposed malignant œdema, the fluid from the affected tissues ought first to be examined microscopically, to ascertain the characters of the organisms present. It is, however, not possible to identify absolutely the bacillus of malignant œdema without cultivating it. For purposes of separating the organism, roll tubes of glucose gelatine may be made at once, and kept under anærobic conditions (p. 64). If the supposed malignant œdema bacilli contain spores, the fluid should be first exposed to a temperature of 80° C. for ten minutes, and then a deep glucose agar tube should be inoculated. In this way the spore-free organisms are killed off. Pure cultures may be thus obtained, or this procedure may require to be followed by the roll tube method. An inoculation experiment, if available, may also be made on a guinea-pig.

Quarter-evil (German, Rauschbrand; French, Charbon Symptomatique).

The characters of the bacillus need be only briefly described, as, so far as is known, it never infects the human subject. The natural disease, which specially occurs in certain localities, affects chiefly sheep, cattle, and goats. Infection takes place by some wound of the surface, and there spreads in the region around, inflammatory swelling attended by bloody œdema and emphysema of the tissues. The part becomes greatly swollen, and of a dark, almost black, colour. Hence the name "blackleg" by which the disease is sometimes known. The bacillus which produces this condition is present in large numbers in the affected tissues, associated with other organisms, and also occurs in small numbers in the blood of internal organs.

The bacillus morphologically closely resembles that of malignant œdema. It is, however, somewhat thicker, and does not usually form such long filaments. Like the latter, also, it is a strict anærobe, and its conditions of growth as regards temperature are also similar. The

characters of the cultures, also, resemble those of the bacillus of malignant œdema, but the growth in gelatine, before liquefaction occurs, has a more compact appearance. It also forms spores, which are usually situated close to the ends of the rods, and are broader than the latter (Fig. 91). It is actively motile, and possesses numerous lateral flagella.

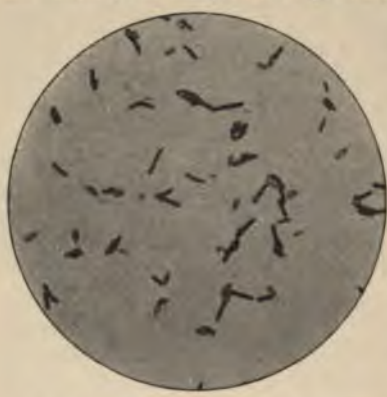

FIG. 91.—Bacillus of quarter-evil, showing spores. From a culture in glucose agar, incubated for three days at 37° C. Stained with weak carbol-fuchsin. × 1000.

The disease can be readily produced in various animals—guinea-pigs, rabbits, etc., by inoculation with the affected tissues of diseased animals, and also by means of pure cultures, though a considerable amount of the latter is usually necessary. The condition produced in this way closely resembles that in malignant œdema, though there is said to be more formation of gas in the tissues. Rabbits are much more susceptible to this affection than to malignant œdema.

The disease is one against which immunity can be readily produced in various ways, and methods of preventive inoculation have been adopted in the case of animals liable to suffer from it. This subject was specially worked out by Arloing, Cornevin, and Thomas, and later by others. Immunity may be produced by injection with a non-fatal dose of the virus, or by injection with larger quantities of the virus attenuated by heat, drying, etc. It can be produced also by the products of the bacilli obtained by filtration of cultures.

CHAPTER XVII.

CHOLERA.

Introductory.—It is no exaggeration of the facts to say that previously to 1883 practically nothing of value was known regarding the nature of the virus of cholera. In that year Koch was sent to Egypt, where the disease had broken out, in charge of a commission for the purpose of investigating its nature. In the course of his researches he discovered the organism now generally known as the "comma bacillus" or the "cholera spirillum." He found this organism in the discharges from the intestine, and also *post mortem* in the intestinal contents and in certain parts of the intestinal mucous membrane. Later he made more extensive observations in India, and also investigated two cases at Toulon, nearly 100 cases in all being examined, and came to the conclusion that the association of this organism with the disease was constant. The organism, moreover, was one which was quite unknown before, and numerous observations made in other diseased conditions failed to show its presence. He also obtained pure cultures of the organism from a large number of cases of cholera, and described their characters. The results of his researches were given at the first Cholera Conference at Berlin in 1884. Next year he brought forward experiments on animals which, he considered, supported his view as to the relationships of the organism to the disease. The general conclusions at which Koch arrived received, in the

main, confirmation from the investigations of others, though some criticism arose, especially as regards the uniformity of the characters of the comma bacillus.

Within recent years, and especially during the epidemic in Europe in 1892-93, spirilla have been cultivated from cases of cholera in a great many different localities, and though this extensive investigation has revealed the invariable presence in true cholera of organisms resembling more or less closely Koch's spirillum, certain difficulties have arisen. For it has been found that the cultures obtained from different places have shown considerable variations in their characters, and, further, spirilla which closely resemble Koch's cholera spirillum have been cultivated from sources other than cases of true cholera. There has therefore been much controversy, on the one hand as to the signification of these variations—whether they constitute different species, or whether they are to be regarded merely as indicating varieties of the same species, and on the other hand as to the means of distinguishing the cholera spirillum from other species which resemble it.

We shall first give an account of the characters of the cholera spirillum, with the evidence for its causal relationship to the disease, and afterwards discuss some of the questions just referred to. It may, however, be stated here that no other organism of any kind has been discovered which has even the faintest claim to be the cause of the disease.

In considering the bacteriology of cholera it is to be borne in mind that in this disease, in addition to the evidence of great intestinal irritation, accompanied by profuse watery discharge, and often by vomiting, there are also symptoms of general systemic disturbance which cannot be accounted for merely by the withdrawal of water and certain substances from the system. Such symptoms include the profound general prostration, cramps in the muscles, extreme cardiac depression, the cold and clammy condition of the surface, the subnormal temperature, suppression of urine, etc. These taken in their entirety are indications of a general poisoning in which the circulatory and thermo-

regulatory mechanisms are specially involved. In some, though rare, cases known as *cholera sicca*, general collapse occurs with remarkable suddenness, and is rapidly followed by a fatal result, whilst there is little or no evacuation from the bowel, though *post mortem* the intestine is distended with fluid contents. As the characteristic organisms in cholera are found only in the intestine, the general disturbances are to be regarded as the result of toxic substances absorbed from the bowel. It is also to be noted that cholera is a disease of which the onset and course are much more rapid than is the case in most infective diseases, such as typhoid and diphtheria; and that recovery also, when it takes place, does so more quickly. The two factors to be correlated to these facts are (*a*) a rapid multiplication of organisms, (*b*) the production of rapidly acting toxines.

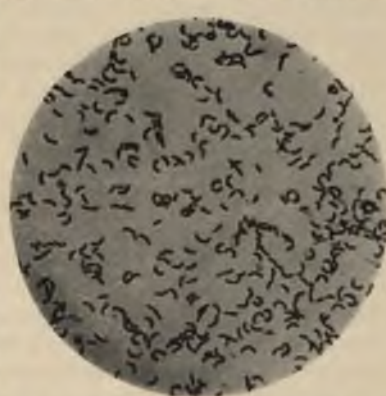

FIG. 92. — Cholera spirilla, from a culture on agar of twenty-four hours' growth. Stained with weak carbol-fuchsin. × 1000.

The Cholera Spirillum. Microscopical Characters. — The cholera spirilla as found in the intestines in cholera are small organisms measuring about 1.5 to 2 μ in length, and rather less than .5 in thickness. They are distinctly curved in one direction, hence the appearance of a comma (Fig. 92); most occur singly, but some are attached in pairs and curved in opposite directions, so that an S-shape results. Longer forms are rarely seen in the intestine, but in cultures in fluids, as is especially well seen in hanging-drop preparations, they may grow into longer spiral filaments, showing a large number of turns. If film preparations be made from the

intestinal contents in typical cases, it will be found that these organisms are present in enormous numbers in almost pure culture, and that most of the spirilla lie with their long axis in the same direction, so as to give the appearance which Koch compared to a number of fish in a stream.

They possess very active motility, which is most marked in the single forms. When stained by the suitable methods they are seen to be flagellated. Usually a single terminal flagellum is present at one end only (Fig. 93). It is very delicate, and measures four or five times the length of the organism. In some varieties, however, there may be such a flagellum at both ends, and again, more than one may be present. Cultures obtained at different places have shown considerable variations in this respect. Cholera spirilla do not form spores. In old cultures, however, small rounded and highly refractile bodies may be found in the organisms, which have been regarded by Hueppe as "arthrospores," but are in reality merely the result of degeneration, as they have no higher powers of resistance than the spirilla themselves, and cultures containing enormous numbers of such bodies may be found to be quite dead. Along with such appearances in old cultures there is found great change in the size and shape of the organisms. Some are irregularly twisted filaments, sometimes globose, sometimes clubbed at their extremities, and also showing irregular swellings along their course. Others are short and thick, and may have the appearance

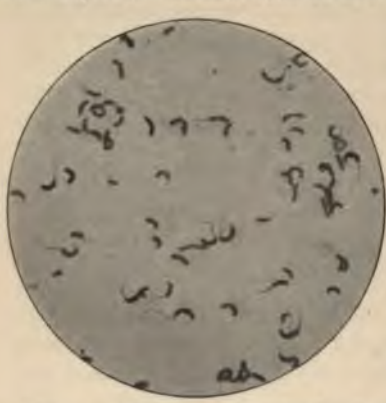

FIG. 93.—Cholera spirilla stained to show the terminal flagella. × 1000.

of large cocci, often staining faintly. All these changes in appearance are to be classed together as *involution forms.*

Staining.—Cholera spirilla stain readily with the usual basic aniline stains, though Löffler's methylene-blue or weak carbol-fuchsin is specially suitable. They lose the stain in Gram's method.

Distribution within the Body.—The chief fact in this connection is that the spirilla are confined to the intestine, and are not present in the blood or internal organs. This was determined by Koch in his earlier work, and his statement has been amply confirmed. In cases in which there is the characteristic "rice-water" fluid in the intestines, they occur in enormous numbers—almost in pure culture. The lower half of the small intestine is the part most affected. Its surface epithelium becomes shed in great part, and the flakes floating in the fluid consist chiefly of masses of epithelial cells and mucus, amongst which are numerous spirilla. The spirilla also penetrate the follicles of Lieberkühn, and may be seen lying between the basement membrane and the epithelial lining, which becomes loosened by their action. They are, however, rarely found in the connective tissue beneath, and never penetrate deeply. Along with these changes there is congestion of the mucosa, especially around the Peyer's patches and solitary glands, which are somewhat swollen and prominent. In some very acute cases the mucosa may show general acute congestion with a rosy pink colour, but very little desquamation of epithelium occurs, the intestinal contents being a comparatively clear fluid containing the spirilla organisms in large numbers. In other cases of a more chronic type, the intestine may show more extensive necrosis of the mucosa and a considerable amount of hæmorrhage into its substance, along with formation of false membrane at places. The intestinal contents in such cases are blood-stained and foul-smelling, there being a great proportion of other organisms present besides the cholera spirilla (Koch).

Cultivation.—(For Methods, see p. 399).

The cholera spirillum grows readily on all the ordinary

media, and with the exception of that on potato, growth takes place at the ordinary room temperature. The most suitable temperature, however, is that of the body, and growth usually stops about 16° C., though in some cases it has been obtained at a lower temperature.

FIG. 94.—Puncture culture of the cholera spirillum in peptone gelatine — six days' growth. Natural size.

Peptone gelatine.—On this medium the organism grows well and produces liquefaction. In puncture cultivations at 22° C. a whitish line appears along the needle track, at the upper part of which liquefaction commences, and as evaporation quickly occurs, a small bell-shaped depression forms, which gives the appearance of an air-bubble. On the fourth or fifth day we get the following appearance: there is at the surface the bubble-shaped depression; below this there is a funnel-shaped area of liquefaction, the fluid being only slightly turbid, but covered on its surface with a more or less complete pellicle, and showing at its lower end thick masses of growth of a more or less spiral shape (Fig. 94). The liquefied portion gradually tapers off downwards towards the needle track. (This appearance is, however, in some varieties not produced till much later, especially when the gelatine is very stiff, and, in other varieties which liquefy very slowly, may not be met with at all.) At a later stage, liquefaction spreads and may reach the side of the tube.

In *gelatine plates* the colonies are somewhat characteristic. They appear as minute whitish points, visible in twenty-four to forty-eight hours, which, under a low power of the microscope, do not present a smooth circular outline, but

one which is irregularly granular or furrowed; as they become larger their surface has an appearance which has been compared to fragments of broken glass. Later, liquefaction occurs, and the colony sinks into the small cup formed, the plate then showing small sharply-marked rings around the colonies. Under the microscope the outer margin of the cup is circular and sharply marked. Within the cup the liquefied portion forms a ring which has a more or less granular appearance, whilst the mass of growth in the centre is irregular and often broken up at its margins. Later still, liquefaction spreads around and the appearance becomes less characteristic. The growth of the colonies in gelatine plates constitutes one of the most important means of distinguishing the cholera spirillum from other organisms.

On the surface of the *agar* media a semi-transparent greyish white layer forms, which presents no special characters. On solidified *blood serum* the growth has at first the same appearance, but afterwards liquefaction of the medium occurs. On agar plates the superficial colonies under a low power are circular discs of brownish-yellow colour, and more transparent than those of most other organisms. On *potato* at the ordinary temperature, growth does not take place, but when it is incubated at a temperature of from 30° to 37° C., a moist layer appears, which assumes a dirty brown colour somewhat like that of the glanders bacillus. It has, however, a greyish-brown rather than a chocolate tint, and moreover the appearance varies somewhat in different varieties, and also on different sorts of potatoes.

In *bouillon* with alkaline reaction the organisms grow very readily, there occurring at 37° C. a general turbidity in twelve hours, whilst the surface shows a thin pellicle composed of the organisms in a very actively motile condition. Growth takes place under the same conditions equally rapidly in peptone solution (1 per cent with .5 per cent sodium chloride added).

In *milk* also the organisms grow well and produce no coagulation nor any change in its appearance, at least for several days.

On all the media the growth of the cholera spirillum is a relatively rapid one, and especially is this the case in the peptone solution named and in bouillon, a circumstance of importance in relation to its separation in cases of cholera (*vide* p. 399).

Another characteristic, though one not peculiar to this organism, is the so-called *cholera-red* reaction. If to a culture in peptone bouillon or solution of peptone (1 per cent), which has grown for twenty-four hours at 37° C., a few drops of pure sulphuric acid are added, a reddish-pink colour is produced. This is due to the fact that indol and a nitrite are formed by the spirillum in the medium. The addition of sulphuric acid causes a nitroso-indol body to be produced from these, and this gives the red colour. It is to be noted that, unlike the case of the B. coli communis where a similar reaction occurs, the addition of a nitrite is here unnecessary, as the nitrite is formed by the organism, probably from the nitrates which are present. Here, as in the case of the negative indol reaction given by the typhoid organism, it is found that not every specimen of peptone is suitable, and it is advisable to select a peptone which gives the characteristic reaction with a known cholera organism, and to use it for further tests. It is also essential that the sulphuric acid should be pure, for if traces of nitrites are present the reaction might be given by an organism which had not the power of forming nitrites. This is one of the most important tests in the diagnosis of the cholera organism. It is always given by a true cholera spirillum, and though the reaction is not peculiar to it, the number of organisms which give the reaction under the conditions mentioned are comparatively few.

The cholera organism is one which grows much more rapidly in the presence of oxygen than in anærobic conditions. Koch, in his earlier work, believed that no growth took place in the absence of oxygen, and it has been recently stated that this is the case in *absolutely* anærobic conditions. Growth, however, takes place in the ordinary anærobic conditions, usually employed in the culture of

anærobic organisms, such as those of tetanus and malignant œdema, though it occurs more slowly than in the presence of oxygen. In the intestines the oxygen supply, though small in amount, is yet sufficient for the growth of the spirilla.

Powers of Resistance.—In their resistance against heat cholera spirilla correspond with spore-free organisms, and are killed in an hour by a temperature of 55° C., and much more rapidly at higher temperatures. They have comparatively high powers of resistance against great cold, and have been found alive after being exposed for several hours to a temperature of – 10° C. They are, however, killed by being kept in ice for a few days. Against the ordinary antiseptics they have comparatively low powers of resistance, and Pfuhl found that the addition of lime, in the proportion of 1 per cent, to water containing the cholera organisms, was sufficient to kill them in the course of an hour.

As regards the powers of resistance in ordinary conditions, the following facts may be stated. In cholera stools kept at the ordinary room temperature, the cholera organisms are rapidly outgrown by putrefactive bacteria, but in some cases they have been found alive even after two or three months. In most experiments, however, attempts to cultivate them after a much shorter time have failed. The general conclusion may be drawn from the work of various observers that the spirilla do not multiply freely in ordinary sewage water, but that in certain circumstances they may live for a considerable period of time. In distilled water they remain alive for several weeks at least, but do not multiply, nor does any considerable growth take place without the presence of a pretty large proportion of organic matter. On moist linen, as Koch showed, they can flourish very rapidly. When the cholera organisms are grown along with other organisms in fluids at a warm temperature, it is found that at first they may multiply more rapidly than the others, but after a certain time they are outgrown by some of the organisms present, gradually diminish in number, and ultimately disappear. It must not, however, be inferred from such experiments that a similar result will necessarily

follow in nature, as any particular saprophytic organism requires a special habitat—that is, certain suitable conditions for its growth in competition with other organisms. Though we can state generally that the conditions favourable for the growth of the cholera spirillum are, a warm temperature, moisture, a good supply of oxygen, and a considerable proportion of organic material, we do not know the exact circumstances under which it can flourish for an indefinite period of time as a saprophyte. The fact that the area in which cholera is an endemic disease is so restricted tends to show that the conditions for a prolonged growth of the spirillum outside the body are not usually supplied. Yet, on the other hand, there is no doubt that in ordinary conditions it can live a sufficient time outside the body and multiply to a sufficient extent, to explain all the facts known with regard to the persistence and spread of cholera epidemics.

Numerous experiments show that the cholera organisms are, as a rule, rapidly killed by drying, usually in two or three minutes when the drying has been thorough, and it is inferred from this that they cannot be carried in the living condition for any great distance through the air, a conclusion which is well supported by observations on the spread of the disease. Cholera is practically always transmitted by means of water or food contaminated by the organism, and there is no doubt that contamination of the water supply by choleraic discharges is the chief means by which areas of population are rapidly infected. It has been shown that if flies are fed on material containing cholera organisms, the organisms may be found alive within their bodies twenty-four hours afterwards. And further, Haffkine found that sterilised milk might become contaminated with cholera organisms, if kept in open jars to which flies had free access, in a locality infected by cholera. It is quite possible that infection may be carried by this method in some cases.

Experimental Inoculation.—In considering the effects of inoculation with the cholera organism, we are met with the

difficulty that none of the lower animals, so far as is known, suffer from the disease under natural conditions. Even in places where cholera is endemic, no corresponding affection has been observed in any animals. And further, before the discovery of the cholera organism, various efforts had been made to induce the disease in animals by feeding them with cholera dejecta, but without success. It is therefore not surprising that the earlier experiments on animals by feeding them with pure cultures were attended with negative results. As the organisms are confined to the alimentary tract in the natural disease, attempts to induce their multiplication within the intestine of animals by artificially arranging favouring conditions, have occupied a prominent place in the experimental work.

Nikati and Rietsch were the first to inject the organisms directly into the duodenum of dogs and rabbits, and they succeeded in producing, in a considerable proportion of the animals, a choleraic condition of the intestine; in their earlier experiments the common bile duct was ligatured, but the later were performed without this operation. These experiments were confirmed by other observers, including Koch. Thinking that probably the organisms, when introduced by the mouth, are destroyed by the action of the hydrochloric acid of the gastric secretion, Koch first neutralised this acidity by administering to guinea-pigs 5 c.c. of a 5 per cent solution of carbonate of soda, and sometime afterwards fed the animals with the organisms, or introduced a fluid culture into the stomach by means of a tube. Of nineteen animals treated in this way, only one died with choleraic changes in the small intestine. This animal had aborted a short time previously, and its abdominal walls were very relaxed, and Koch considered that, in some way at least, the intestinal peristalsis had been interfered with, and thus opportunity had been afforded to the organisms of gaining a foothold and multiplying in the intestine. He accordingly tried the effect of artificially interfering with the intestinal peristalsis by injecting tincture of opium into the peritoneum (1 c.c. per 200 grm. weight),

in addition to neutralising as before with the carbonate of sodium solution. The result was remarkable, as thirty, out of thirty-five animals treated, died with the same changes as in the single animal in the previous series of experiments. He afterwards repeated the experiments on a larger scale, with the same result. When the animals become infected by this method they show signs of general prostration, their posterior extremities being especially weakened; their abdomen becomes tumid, respiration slow, heart's action weak, and the surface cold. Death occurs after a few hours. *Post mortem* the small intestine is distended, its mucous membrane congested, and it contains a colourless fluid with small flocculi and the cholera organisms in practically pure cultures. The intestinal contents from one of the affected animals could produce a similar diseased condition in another animal treated in the same way. These experiments, which have been repeatedly confirmed, therefore demonstrated that the cholera organisms could, under certain conditions, set up in animals a condition in some respects resembling cholera. Koch, however, found that when the spirilla of Finkler and Prior, of Deneke, and of Miller (*vide infra*) were employed by the same method, a certain, though much smaller, proportion of the animals died from an intestinal infection. Though the changes in these cases were not of so characteristic a nature, they were sufficient to prevent the results obtained with the cholera organism from being used as a demonstration of the specific relation of the latter to the disease.

Within the last few years some additional facts of high interest have been established with regard to choleraic infection of animals. For example, Sabolotny found that in the marmot an intestinal infection readily takes place by simple feeding with the organism, there resulting the usual intestinal changes, sometimes with hæmorrhagic peritonitis, the organisms, however, being present also in the blood. It was found by Issaeff and Kolle that young rabbits could be infected by merely neutralising the gastric secretion with sodium carbonate, the use of opium being unnecessary; but

of special interest is the fact, discovered by Metchnikoff, that in the case of young rabbits shortly after birth, a large proportion die of choleraic infection when the organisms are simply introduced along with the milk, as may be done by infecting the teats of the mother. Further, from these animals thus infected the disease may be transmitted to others by a natural mode of infection. In this affection of young rabbits many of the symptoms of cholera are present—great prostration, markedly subnormal temperature, sometimes anuria, and occasionally slight cramps before death. Most frequently there is diarrhœa, though sometimes this may be absent, death occurring after the other symptoms, the group of phenomena, according to Metchnikoff, corresponding with *cholera sicca*. The small intestine, especially in its lower part, shows the most marked changes, though the cæcum also is distended with fluid. The organisms occur in large numbers in these parts, and in some cases a few may be found in the blood, and especially in the gall bladder. Many of these experiments were performed with the vibrio of Massowah, which is now admitted not to be a true cholera organism, others with a cholera vibrio obtained from the water of the Seine.

It will be seen from the above account that the evidence obtained from experiments on intestinal infection of animals, though by no means sufficient to establish the specific relationship of the cholera organism, is on the whole favourable to this view, especially when it is borne in mind that animals do not in natural conditions suffer from the disease.

Experiments performed by direct inoculation also supply interesting facts. *Intraperitoneal* injection in guinea-pigs is followed by general symptoms of illness, the most prominent symptoms being distention of the abdomen, subnormal temperature, and, ultimately, profound collapse. There is peritoneal effusion, which may be comparatively clear, or may be somewhat turbid and contain flakes of lymph, according to the stage at which death takes place. If the dose is large, organisms are found in considerable

numbers in the blood and also in the small intestine, but with smaller doses they are practically confined to the peritoneum. Kolle found that when the minimum lethal dose was used in guinea-pigs, the peritoneum might be free from organisms at the time of death, the fatal result having taken place from an intoxication. In rabbits, after *intravenous* injection of comparatively large quantities, death may follow within eighteen hours, with symptoms of general intoxication; the organisms are present in the blood, though rather diminished in number, and few are to be found in the intestine. If, however, the dose is smaller and the animals live longer, then the organisms may settle and multiply in the intestine, and changes quite analogous to those in cholera are produced—congestion of mucous membrane, and at places desquamation of epithelium (Issaeff and Kolle). In the case of animals which die when these changes have occurred, the organisms may have quite disappeared from the blood and internal organs. These experiments show that though the organisms undergo a certain amount of multiplication when introduced by the channels mentioned, still the tendency to invade the tissues is not a marked one. On the other hand the symptoms of general intoxication are always pronounced. Hence arise questions as to the nature and mode of action of toxic bodies produced by the cholera organism.

Toxines.—Though there is no doubt that there are formed by Koch's spirillum toxic bodies which produce many of the symptoms of cholera, there is at present very little satisfactory knowledge regarding their chemical nature. The following summary may be given.

It has been shown, especially by R. Pfeiffer,[1] that toxic phenomena can be produced by injection of the *dead vibrios* into animals. A certain quantity of a young culture on agar, killed by exposure to the vapour of

[1] Pfeiffer obtained his earlier results with a vibrio from Massowah, which is now known not to be a true cholera organism. This fact shows that the effects described are not specific to the latter.

chloroform, when injected intraperitoneally into a guinea-pig, may cause death in from eight to twelve hours, with symptoms which are comparable with those produced in intestinal infection by Koch's method. There is extreme collapse, sometimes clonic spasms occur, and the temperature may fall below 30° C. before death. Pfeiffer considers that the toxic substances are contained in the bodies of the organisms, that is, they are intracellular, and that they are only set free by the disintegration of the latter. This opinion is grounded chiefly on the fact that when bouillon cultures were filtered, he found that the filtrate possessed very feeble toxic properties. The dead cultures administered by the mouth produce no effect unless the intestinal epithelium is injured, when poisoning may result. He considers that the desquamation of the epithelium is an essential factor in the production of the phenomena of the disease in the human subject. Pfeiffer found that the toxic bodies were to a great extent destroyed at 60° C., but even after heating at 100° C. a small proportion of toxine remained, which had the same physiological action.

On the other hand, other observers (Petri, Ransom, Klein, and others) have obtained toxic bodies from *filtered cultures*. Recently Metchnikoff, E. Roux, and Taurelli-Salimbeni have demonstrated the formation of diffusible toxic bodies in fluid media in the following manner. Small collodion sacs were prepared, each containing 2 to 4 c.c. of bouillon. One sac was inoculated with a living virulent culture of the cholera vibrio; to the second, two entire cultures on agar of the same organism were added, the cultures being first killed by chloroform. Each sac was then closed and placed with aseptic precautions in the peritoneum of a guinea-pig. The animal which received the sac containing the living vibrios soon showed symptoms of choleraic poisoning, and died in a few days, whilst the animal which received the sac containing large quantities of dead organisms only showed transitory symptoms of illness. The experimenters therefore concluded that toxic substances are formed by the living organisms,

which quickly diffuse into the medium (and in the experiments, through the wall of the sac). By greatly increasing the virulence of the organism, then growing it in bouillon and filtering the cultures on the third and fourth day, they obtained a fluid which was highly toxic to guinea-pigs (the fatal dose usually being $\frac{1}{5}$ c.c. per 100 grm. weight). If the dose of the toxine is very large, death follows in an hour or even less. The symptoms closely resemble those obtained by Pfeiffer, the rapid fall of temperature being a striking feature. *Post mortem* at the site of inoculation there is a little inflammatory œdema, the internal organs are congested, and the small intestine is distended with fluid contents. The toxicity of the filtrate they found not to be altered by boiling. It is somewhat difficult to reconcile the results of Pfeiffer and Metchnikoff as regards the action of heat, though probably the toxine obtained by Metchnikoff corresponds with the secondary body of Pfeiffer, which he obtained in small quantities. A considerable number of observers, however, agree in stating that the toxines obtained by them from cholera cultures are not destroyed at 100° C.

A great many observers have attempted to obtain toxines in a chemically pure condition, but so far without results which can be regarded as conclusive. Hueppe and Wood found that the most active toxines were produced by growing the cholera organism in albumin in anærobic conditions, and considered that this corresponded to the mode of their production in cholera. Scholl confirmed Hueppe's results, and obtained from cultures under such conditions a peptone which possessed high toxic properties, and which he called cholera toxopeptone. These results, however, have been adversely criticised by various observers. Wesbrook obtained different substances according to the media on which the cholera organisms were grown, and yet these produced very much the same effects, chiefly collapse, subnormal temperature, cramps, dyspnœa, etc. Such toxic bodies were even obtained from cultures in asparaginate of soda, which did not contain any proteid substance. He therefore came to the conclusion that so-called toxalbumins etc. are really mixtures of albumins and true toxines, the chemical nature of the latter not having been yet determined. Wesbrook also obtained the toxic bodies in small quantity from the pleural exudate of guinea-pigs killed by the vibrio. Bosq also found that the blood, and to a less extent the urine, of patients who had died

in the algid stage, produce toxic phenomena and death, when injected intravenously in rabbits. In this case also, nothing is known with regard to the chemical nature of the toxic bodies.

Experiments on the Human Subject.—Experiments have also been performed in the case of the human subject, both intentionally and accidentally. In the course of Koch's earlier work, one of the workers in his laboratory shortly after leaving was seized with severe choleraic symptoms, attended with watery evacuations, etc. The stools were found to contain cholera spirilla in enormous numbers. Recovery, however, took place. In this case there was no other conceivable source of infection than the cultures with which the man had been working, as no cholera was present in Germany at the time. Within recent years a considerable number of experiments have been performed on the human subject, which certainly show that in some cases more or less severe choleraic symptoms may follow ingestion of pure cultures, whilst in others no effects may result. The former was the case, for example, with Emmerich and Pettenkofer, who made experiments on themselves, the former especially becoming seriously ill. In the case of both, diarrhœa was well marked, and numerous cholera spirilla were present in the stools, though toxic symptoms were proportionately less pronounced. Metchnikoff also by experiments on himself and others obtained results which convinced him of the specific relation of the cholera spirillum to the disease. Lastly, the case of Dr. Örgel in Hamburg may be noted, who contracted the disease in the course of experiments with the cholera and other spirilla, and died in spite of treatment. It is believed that in sucking up some peritoneal fluid containing cholera spirilla, a little entered his mouth and thus infection was produced. This took place in September 1894 at a time when there was no cholera in Germany. On the other hand, in many cases the experimental ingestion of cholera spirilla by the human subject has given negative results. Still, as the result of observation of what takes place in a cholera epidemic, it is the general opinion of authorities that only a certain proportion of people are

susceptible to the disease, and the facts mentioned above have, in our opinion, a great weight in establishing the relation of the organism to the disease.

Immunity.—As this subject is discussed later, only a few facts will be here stated, chiefly for the purpose of making clear what follows with regard to the means of distinguishing the cholera spirillum from other organisms. The guinea-pig or any other animal may be easily immunised against the cholera organism by repeated injections (conveniently made into the peritoneum) of non-fatal doses of the organism. It is better to commence the process with non-fatal doses of cultures killed by the vapour of chloroform or by heat, the doses being gradually increased, and afterwards to proceed with increasing doses of the living organism. In this way a high degree of immunity against the organism is developed, and further, the blood serum of an animal thus immunised (anti-cholera serum) has markedly protective power when injected, even in a small quantity, into a guinea-pig along with five or ten times the fatal dose of the living organism. The blood serum of an animal immunised against the cholera organism has, however, no special protecting power against another species of organism. This constitutes the principle of Pfeiffer's method of diagnosis to be described.

A curious fact, however, is, that immunity produced by the above method is only exerted against the living organisms, and does not protect against the toxines, that is, it is due to certain substances which act as germicides (indirectly), but are not antitoxic. Further, it does not protect the guinea-pig from the intestinal infection by Koch's method (Pfeiffer and Wassermann, Sobernheim, Klein), nor does the anti-cholera serum protect young rabbits against the choleraic affection produced by ingestion of the cholera vibrios (Metchnikoff). The inference from these latter results appears to be, that when the vibrios are introduced into the tissues, they are killed by certain substances in the serum, but in the intestine they are in a sense outside of the tissues, and can there multiply and produce toxines.

Metchnikoff has prepared a true antitoxic cholera serum by injections of repeated and gradually increased doses of the toxine, and has found that this antitoxic serum has a distinct effect against the choleraic affection of rabbits.

For Haffkine's method of *preventive inoculation* vide chapter on Immunity.

Means of Distinguishing the Cholera Organism.—According to Koch the most important points in the diagnosis of cholera are:—

(*a*) Microscopical characters of the dejecta. (*b*) Appearance of the colonies in gelatine plates. (*c*) Their appearance on agar plates. (*d*) The growth in peptone solution. (*e*) The cholera-red reaction. (*f*) The effect of intraperitoneal inoculation of guinea-pigs with pure cultures.

There can be no doubt that in the great majority of cases these points taken collectively are sufficient, but difficulties have arisen, as in some cases of apparently true cholera the cultures obtained have shown variations, and on the other hand, there have been cultivated from other sources spirilla which only differ from the cholera spirillum in a few minor points. Pfeiffer has accordingly introduced the method of diagnosis referred to above, which depends on the principle that the serum of an animal highly immunised against the cholera spirillum (anti-cholera serum) will protect another animal against that organism only. Further, he has found that a striking change is observed microscopically in the vibrios when injected along with the protective serum into the peritoneal cavity of another guinea-pig—Pfeiffer's reaction. Pfeiffer's principle so far may be said to involve an assumption, though there is a considerable amount of evidence that the assumption is correct. The method is as follows: A loopful (2 mgrm.) of recent agar culture of the organism to be tested is added to 1 c.c. of ordinary bouillon containing .001 c.c. of anti-cholera serum. The mixture is then injected into the peritoneal cavity of a young guinea-pig (about 200 grm. in weight), and the peritoneal fluid of this animal (conveniently

obtained by means of capillary glass tubes inserted into the peritoneum) is examined microscopically after a few minutes. If the spirilla injected have been cholera spirilla, it will be found that they become motionless, swell up into globules, and ultimately break down and disappear—*positive result.* If they are found active and motile, then the possibility of their being true cholera spirilla may be excluded—*negative result.* In the former case (positive result) there is, however, still the possibility that the organism is devoid of pathogenic properties and has been destroyed by the normal peritoneal fluid. A control experiment should accordingly be made with .001 c.c. of normal serum in place of the anti-cholera serum. If no alteration of the organism occurs with its use, then it is to be concluded that the organism in question has been demonstrated by the specific reaction to be the cholera spirillum. Bordet, and Gruber and Durham, have since devised methods by which a corresponding reaction can be observed outside the body (see Chap. XIX.). Further experiments are necessary to show what the exact worth of this reaction is, but extensive observations made up to the present time, especially those of Dunbar conducted on a large series of spirilla, are on the whole distinctly in favour of Pfeiffer's statement being a general law. This method makes the effects of the vital activity of the organism the criterion for distinguishing it from others, and, so far as the production of the disease is concerned, this appears quite rational. It still remains to be seen how far distinction by this means corresponds with differences in cultures. Difficulties may arise when the cholera organism has been grown for a long time outside the body and has lost its virulence.

Properties of the Serum of Patients Convalescent from Cholera.—Lazarus was the first to show that the serum of patients who had suffered from cholera, possessed the power of protecting guinea-pigs, when injected in very minute quantity along with a fatal dose of the cholera organism. These experiments have been confirmed by

Klemperer, Issaeff, and Pfeiffer, and the last mentioned found that the serum of such patients when used in the same way as the serum of highly-immunised animals gave the characteristic reaction if injected with the vibrios into the peritoneal cavity of a guinea-pig. In other words, certain bodies are developed in the blood which exert a protecting power against the cholera organism. Further, so far as experiment has gone, this action is not exerted against any other organism, that is, it is specific towards the cholera spirillum. This action of the serum may be present eight or ten days after the attack of the disease, but is most marked four weeks after; it then gradually becomes weaker and disappears in two or three months (Pfeiffer and Issaeff). Needless to say, this is another strong argument in favour of Koch's spirillum being the cause of cholera, the facts established being quite analogous to those observed in the case of typhoid fever.

Klemperer also found that after several injections of dead cultures of the cholera spirillum in the human subject, the blood serum possessed considerable protective power when tested along with the organism in a guinea-pig, though the protective power observed by him was not so great as that found after an attack of the natural disease.

General Summary. — We may briefly summarise as follows the facts in favour of Koch's spirillum being the cause of cholera. *First*, there is the constant presence in true cases of cholera of spirilla which on the whole conform closely with Koch's description, though variations undoubtedly occur. Moreover, the facts known with regard to their conditions of growth, etc., are in conformity with the origin and spread of cholera epidemics. *Secondly*, the experiments on animals with Koch's spirillum or its toxines give as definite results as one can reasonably look for in view of the fact that animals do not suffer naturally from disease. *Thirdly*, the experiments on the human subject and the results of accidental infection by means of pure cultures are also strongly in favour of this view. *Fourthly*, the specific protecting power of the serum of convalescents

from cholera is another point in its favour, though further evidence under this head is desirable. *Fifthly*, bacteriological methods, which proceed on the assumption that Koch's spirillum is the cause of the disease, have been of the greatest value in the diagnosis of the disease. And *lastly*, the results of Haffkine's method of preventive inoculation in the human subject, which are on the whole favourable, also supply additional evidence. If all these facts are taken together, we consider the conclusion must be arrived at that the growth of Koch's spirillum in the intestine is the immediate cause of the disease. This does not exclude the probability of an important part being played by conditions of weather and locality, though such are very imperfectly understood. Pettenkofer, for example, recognises two main factors in the causation of epidemics, which he designates x and y, and considers that these two must be present together in order that cholera may spread. The x is the direct cause of the disease—an organism, which he now admits to be Koch's spirillum; the y includes climatic and local conditions, *e.g.*, state of ground-water etc.

Difficulty does not arise, however, so much with regard to the causal relationship of Koch's spirillum to cholera as in connection with various organisms which have been cultivated from other sources, and which more or less closely resemble it.

Other Spirilla Resembling the Cholera Organism.—These have been chiefly obtained either from water contaminated by sewage or from the intestinal discharge in cases with choleraic symptoms. Some of them differ so widely in their cultural and other characters (some, for example, are phosphorescent) that no one would hesitate to classify them as distinct species. Others, however, closely resemble the cholera organism.

The *vibrio berolinensis*, cultivated by Neisser from Berlin sewage water, differs from the cholera organism only in the appearance of its colonies in gelatine plates, its weak pathogenic action, and its giving a negative result with Pfeiffer's test. It, however, gives the cholera-red reaction. The *vibrio Danubicus*, cultivated by Heider from canal water, also differs in the appearance of its colonies in plates, and also

reacts negatively to Pfeiffer's test; in most respects it closely resembles the cholera organism. Another spirillum (*v. Ivanoff*) was cultivated by Ivanoff from the stools of a typhoid patient after these had been diluted with water. This organism differed somewhat in the appearance of its colonies and in its great tendency to grow out in the form of long threads, but Pfeiffer found that it reacted to his test in the same way as the cholera organism, and he considered that it was really a variety of the cholera organism. No spirilla could be found microscopically in the stools in this case, and Pfeiffer is of the opinion that the organism gained entrance accidentally. These examples will show how differences of opinion, even amongst authorities, might arise as to whether a certain spirillum were really the cholera organism or a distinct species resembling it in some respects.

A few examples may also be given of organisms cultivated from cases in which cholera-like symptoms were present.

The *vibrio of Massowah* was cultivated by Pasquale from a case during a small epidemic of cholera. This organism so closely resembles Koch's spirillum that it was accepted by several authorities as the true cholera organism, and, as already stated, Metchnikoff produced by it cholera symptoms in the human subject, and also the cholera-like disease in young rabbits. It possesses four flagella, has a high degree of virulence, producing septicæmia both in guinea-pigs and pigeons, and its colonies in plates differ somewhat from the cholera organism. Moreover, it reacts negatively to Pfeiffer's test. Another organism, the *v. Gindha*, was cultivated by Pasquale from a well, and was at first accepted by Pfeiffer as the cholera organism, but afterwards rejected, chiefly because it failed to give the specific immunity reaction. It also differs somewhat from the cholera organism in its pathogenic effects, and it fails to give the cholera-red reaction or gives it very faintly.

Pestana and Bettencourt also cultivated a species of spirillum from a number of cases during an epidemic in Lisbon—an epidemic in which there were symptoms of gastro-enteritis, although only in a few instances did the disease resemble cholera. They also cultivated the same organism from the drinking water. It differs from the cholera organism in the appearance of its colonies and of puncture cultures in gelatine. It has very feeble pathogenic effects, and gives a very faint, or no, cholera-red reaction. To Pfeiffer's test it also reacts negatively. Another spirillum (*v. Romanus*) was obtained by Celli and Santori from twelve out of forty-four cases where there were the symptoms of mild cholera. This organism does not give the cholera-red reaction, nor is it pathogenic for animals. They look upon it as a "transitory variety" of the cholera organism, though sufficient evidence for this view is not adduced.

We have mentioned these examples in order to show some of the difficulties which exist in connection with this subject. There is still considerable doubt as to what tests are sufficient to distinguish Koch's spirillum from others closely resembling it, and even as to whether Pfeiffer's reaction can be accepted as an absolute means of diagnosis. It is important to note that, on the one hand, spirilla which have been judged to be of different species from the cholera organism, have been cultivated from cases in which cholera-like symptoms were present, and on the other hand, in cases of apparently true cholera considerable variations in the characters of the cholera organisms have been found. Such variations have especially been recorded by Surgeon-Major Cunningham in India. It is therefore quite an open question whether some of the organisms in the former case may not be cholera spirilla which have undergone variations as a result of the conditions of their growth. That such variations may occur we have a considerable amount of evidence. The subject is made still more difficult by the results of Sanarelli, who states that he has cultivated from contaminated river water a number of vibrios which conform in all their characters to those of Koch's spirillum and which have also the same pathogenic effects on animals, and also others which differ only in minor points, so that they may be regarded merely as varieties.

In spite of what has been stated above, the great bulk of evidence goes to show that Asiatic cholera always spreads as an epidemic from places in India where the disease is endemic, and that its direct cause is Koch's spirillum. It is sufficient to bear in mind that the choleraic symptoms may be produced by other causes, and that in some of these cases spirilla which have some resemblance to Koch's organism may be present in the intestinal discharges, though rarely in large numbers. In such cases the disease is usually of a comparatively mild nature and remains local, never spreading widely as an epidemic.

Methods of Diagnosis.—In the first place, the stools ought to be examined microscopically. Dried film preparations should be made and stained by any ordinary stains, though carbol-fuchsin diluted four times with water is specially to be recommended. Hanging-drop preparations, with or without the addition of a weak watery solution of gentian-violet or other stain, should also be made, by which method the motility of the organism can be readily seen. By microscopic examination the presence of spirilla will be ascertained, and an idea as to their number obtained. In some cases the cholera spirilla are so numerous in the stools that a picture is presented which is obtained in no other condition, and a microscopic examination may be sufficient for practical purposes. According to Koch, a diagnosis was made in 50 per cent of the cases during the Hamburg epidemic by microscopic examination alone.

If the organisms are very numerous, gelatine or agar plates may be made at once and pure cultures obtained.

If the spirilla occur in comparatively small numbers, the best method is to inoculate peptone solution (1 per cent) and incubate for eight to twelve hours. At the end of that time the spirilla will be found on microscopic examination in enormous numbers at the surface, and thereafter plate cultures can readily be made. If the spirilla are very few in number, or if a suspected water is to be examined for cholera organisms, the peptone solution which has been inoculated should be examined at short intervals till the spirilla are found microscopically. A second flask of peptone solution should then be inoculated, and possibly again a third from the second. By this method, properly carried out, a culture may be obtained which, though impure, contains a large proportion of the vibrios, and then plate cultures may be made.

When a spirillum has been obtained in pure condition by these methods, the appearance of the colonies in plates should be specially noted, the test for the cholera-red reaction should be applied, and in many cases it is advisable to test the effects of intraperitoneal injection of a portion of a

recent agar culture in a guinea-pig, the amount sufficient to cause death being also ascertained. The immunity test should, of course, be employed, where this is possible.

A number of other spirilla have been cultivated, which are of interest on account of their points of resemblance to the cholera organism, though probably they produce no pathological conditions in the human subject.

Metchnikoff's Spirillum (vibrio Metchnikovi).— This organism was obtained by Gamaleia from an epidemic disease of fowls in Odessa, and is of special interest on account of its close resemblance to the cholera organism. In the natural disease, which especially affects young fowls, the animals suffer from diarrhœa, pass into a sort of stupor, sitting with their feathers ruffled, and usually die within forty-eight hours. The intestines contain a greyish-yellow fluid, sometimes slightly blood-stained, in which the spirilla are found. A few of these spirilla may also be found in the blood in the younger fowls, though generally absent from the blood in the older.

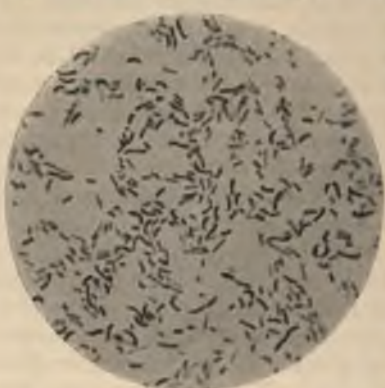

FIG. 95.—Metchnikoff's spirillum, both in curved and straight forms; from an agar culture of twenty-four hours' growth. Stained with weak carbol-fuchsin. × 1000.

Morphologically the organism is practically identical with Koch's spirillum (Fig. 95). It is actively motile, and has the same staining reactions. Its growth in peptone-gelatine also closely resembles that of the cholera organism, though it produces liquefaction more rapidly (Fig. 96, A). In gelatine plates the young colonies are, however, smoother and more circular. After liquefaction occurs, some of the colonies

are almost identical in appearance with those of the cholera organism, whilst others show more uniformly turbid contents. In puncture cultures the growth takes place more rapidly, but in appearance closely resembles that of the cholera organism a few days older. Its growth in peptone solution too is closely similar, and it also gives the cholera-red reaction.

This organism can, however, be readily distinguished from the cholera organism by the effects of inoculation on animals, especially on pigeons and guinea-pigs. Subcutaneous inoculation of small quantities of pure culture in pigeons is followed by acute inflammatory swelling with degeneration of the subjacent muscles, and septicæmia occurs, which produces a fatal result usually within twenty-four hours, the organism being present in the blood. There may be some desquamation of the intestinal epithelium, but only a few organisms are present in the bowel. Inoculation with the same quantity of cholera organism produces practically no result; even with large quantities death is rarely produced. The vibrio Metchnikovi produces somewhat similar effects in guinea-pigs, subcutaneous inoculation being followed by extensive hæmorrhagic

FIG. 96.—Puncture cultures in peptone-gelatine.

A. Metchnikoff's spirillum. Five days' growth.

B. Finkler and Prior's spirillum. Four days' growth. Natural size.

œdema, and a rapidly fatal septicæmia. Young fowls can be infected by feeding with virulent cultures, and guinea-pigs, too, sometimes contract a similar disease without any special preparation, *e.g.*, by neutralising the gastric contents, etc. We have evidence from the work of Gamaleia that the toxines of this organism have somewhat the same action as those of the cholera organism.

The organism is therefore one which very closely resembles the cholera organism, the difference in the effect on inoculating the pigeon offering the most ready means of distinction. It gives a negative reaction to Pfeiffer's test; that is, the properties of an anti-cholera serum are not exerted against it. It may also be mentioned that an organism which is apparently the same as the vibrio Metchnikovi was cultivated by Pfuhl from water, and named v. Nordhafen.

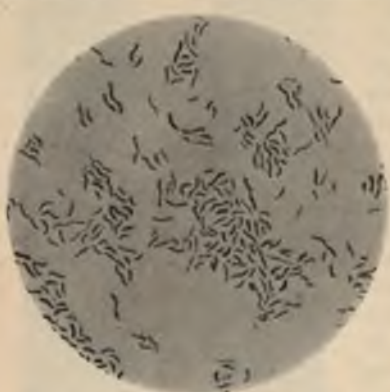

FIG. 97.—Finkler and Prior's spirillum, from an agar culture of twenty-four hours' growth.
Stained with carbol-fuchsin. × 1000.

Finkler and Prior's Spirillum.—These observers, shortly after Koch's discovery of the cholera organism, separated a spirillum, in a case of *cholera nostras*, from the stools after they had been allowed to decompose for several days. Morphologically this organism closely resembles Koch's spirillum, and cannot be distinguished from it by its microscopical characters, although, on the whole, it tends to be rather thicker in the centre and more pointed at the ends (Fig. 97). In cultures, however, it presents marked differences. In puncture cultures on gelatine it grows

much more quickly, and liquefaction is generally visible within twenty-four hours. The liquefaction spreads rapidly, and usually in forty-eight hours it has produced a funnel-shaped tube with turbid contents, denser below (Fig. 96, B). In plate cultures the growth of the colonies is proportionately rapid. Before they have produced liquefaction around them, they appear, unlike those of the cholera organism, as minute spheres with smooth margins. When liquefaction occurs, they appear as little spheres with turbid contents, which rapidly increase in size. These under a low power of the microscope have granular contents, and sometimes show slight radiate striation at the periphery. The individual colonies may reach a third of an inch in diameter, and ultimately general liquefaction occurs. On potatoes this organism grows well at the ordinary temperature, and in two or three days has formed a slimy layer of greyish-yellow colour, which rapidly spreads over the potato. On all the media the growth has a distinctly fœtid odour. A growth in peptone solution fails to give the cholera-red reaction at the end of twenty-four hours, though later a faint reaction may appear. As stated above, Koch succeeded in producing, by this organism, an intestinal affection in guinea-pigs after neutralising the stomach contents and paralysing the intestine with opium. This occurs in a small proportion of the animals experimented on, and the contents of the intestine, unlike what was found in the case of the cholera organism, were turbid in appearance, and had a markedly fœtid odour. When tested by intraperitoneal injection, its effects are somewhat of the same nature as those of the cholera organism, but its virulence is of a much lower order. There is no evidence that it has any causal relationship to *cholera nostras*, nor to any condition of disease in man.

An organism cultivated by Miller from the cavity of a decayed tooth in a human subject is almost certainly the same organism as Finkler and Prior's spirillum.

Deneke's Spirillum.—This organism was obtained from old cheese, and is also known as the *spirillum tyrogenum*. It

closely resembles Koch's spirillum in microscopic appearances, though it is rather thinner and smaller. Its growth in gelatine is also somewhat similar, but liquefaction proceeds more rapidly, and the bell-shaped depression on the surface is larger and shallower, whilst the growth has a more distinctly yellowish tint. The colonies in plates also show points of resemblance, though the youngest colonies are rather smoother and more regular on the surface, and liquefaction occurs more rapidly than in the case of the cholera organism. The colonies have, on naked-eye examination, a distinctly yellowish colour. The organism does not give the cholera-red reaction, and on potato it forms a thin yellowish layer when incubated above 30° C. When tested by intraperitoneal injection and by other methods it is found to possess very feeble, or almost no, pathogenic properties. Koch found that this organism, when administered through the stomach in the same way as the cholera organism, produced a fatal result in three cases out of fifteen. Deneke's spirillum is usually regarded as a comparatively harmless saprophyte.

CHAPTER XVIII.

INFLUENZA, PLAGUE, RELAPSING FEVER, MEASLES, RHINOSCLEROMA.

Influenza.

The first account of the organism now known as the influenza bacillus was published simultaneously by Pfeiffer, Kitasato, and Canon, in January 1892. The two first-mentioned observers found it in the bronchial sputum, and obtained pure cultures, and Canon observed it in the blood in a few cases of the disease. It is, however, to Pfeiffer's work that we owe most of our knowledge regarding its characters and action. From the facts which have been established concerning it, this organism has strong claims to be considered the specific agent in the disease, though absolute proof is still wanting.

Fig. 98.—Influenza bacilli from a culture on blood agar.
Stained with carbol-fuchsin. × 1000.

Microscopical Characters.—The influenza bacilli as seen

in the sputum are very minute rods not exceeding 1.5 μ in length and .3 μ in thickness. They are straight, with rounded ends, and sometimes stain more deeply at the extremities (Fig. 98). The bacilli occur singly or form clumps by their aggregation, but do not grow into chains. They show no capsule. They take up the basic aniline stains somewhat feebly, and are best stained by a weak solution of carbol-fuchsin applied for 5 to 10 minutes. They lose the stain in Gram's method. They are non-motile, and do not form spores.

Cultivation.—The best medium for the growth of the influenza bacillus is blood-agar (see page 47), which was introduced by Pfeiffer. He obtained growths of the bacilli on agar which had been smeared with influenza sputum, but he failed to get any sub-cultures on the agar media or on serum. The growth in the first cultures he considered to be probably due to the presence of certain organic substances in the sputum, and accordingly he tried the expedient of smearing the agar with drops of blood before making the inoculations. The blood of animals is suitable, as well as human blood. In this way he completely succeeded in attaining his object. The colonies of the influenza bacilli on blood agar appear within twenty-four hours, in the form of minute circular dots almost completely transparent. When numerous, the colonies are scarcely visible to the naked eye, but when sparsely arranged they may reach the size of a small pin's head. This size is generally reached on the second day. The bacilli die out somewhat quickly in cultures, and in order to keep them alive sub-cultures should be made every four to five days. By this method the cultures may be maintained for an indefinite period. They also grow well on agar smeared with a solution of hæmoglobin; growth on the ordinary agar media is slight and somewhat uncertain. A very small amount of growth takes place in bouillon, but it is more marked when a little fresh blood is added. The growth forms a thin whitish deposit at the bottom of the flask. The limits of growth are from 25° to 42° C., the

optimum temperature being that of the body. The influenza bacillus is a strictly aërobic organism.

The powers of resistance of this organism are of a low order. Pfeiffer found that dried cultures kept at the ordinary temperature were usually dead in twenty hours, and that if sputum were kept in a dry condition for two days, all the influenza bacilli were dead. Their duration of life in ordinary water is also short, the bacilli usually being dead within two days. From these experiments Pfeiffer concludes that outside the body in ordinary conditions they cannot multiply, and can remain alive only for a short time. The mode of infection in the disease he accordingly considers to be chiefly by direct contact by means of mucus, etc.

Distribution in the Body.—The bacilli are found chiefly in the respiratory passages in influenza. They may be present in large numbers in the nasal secretion, generally mixed with a considerable number of other organisms, but it is in the small masses of greenish-yellow sputum from the bronchi that they occur in largest numbers, and in many cases almost in a state of purity. They occur in clumps which may contain as many as 100 bacilli, and in the early stages of the disease are chiefly lying free. As the disease advances, they may be found in considerable numbers within the leucocytes, and a large proportion have this position towards the end of the disease. It is a matter of considerable importance, however, that they may persist for weeks in the bronchi after symptoms of the disease have disappeared, and may be detected in the sputum. They also occur in large numbers in the capillary bronchitis and catarrhal pneumonia of influenza, as Pfeiffer showed by means of sections of the affected parts. In these sections he found the bacilli lying amongst the leucocytes, which filled the minute bronchi, and also penetrating between the epithelial cells and into the superficial parts of the mucous membrane. Their presence sets up a marked leucocytic emigration in the peribronchial tissue, the leucocytes passing in large numbers into the

lumen of the tubes and sometimes taking up the bacilli. Other organisms also, especially Fraenkel's pneumococcus, are concerned in the pneumonic conditions following influenza.

In some cases influenza occurs in tubercular subjects, or is followed by tubercular affection, in which cases both influenza and tubercle bacilli may be found in the sputum. In such a condition the prognosis is very grave. Regarding the presence of influenza bacilli in the other pulmonary complications following influenza, much information is still required. Occasionally in the foci of suppurative softening in the lung the influenza bacilli have been found in a practically pure condition. In cases of empyema the organisms present would appear to be chiefly streptococci and pneumococci; whilst in the gangrenous conditions, which sometimes occur, a great variety of organisms has been found.

As above stated, Canon described the bacilli as occurring in the blood, and Pfeiffer, on examining Canon's preparations, admits that the bacilli shown resembled the influenza bacilli. His own observations on a large series of cases convinced him that the organism was very rarely present in the blood, that in fact its occurrence there must be looked upon as exceptional. The conclusions of other observers have, on the whole, confirmed this statement. It has been regularly found in enormous numbers in the sputum in influenza, but only occasionally and in small numbers in the blood. It is probable that the chief symptoms in the disease are due to toxines absorbed from the respiratory tract (*vide infra*).

We cannot yet speak definitely with regard to the relation of the bacillus to other complications in influenza. Pfeiffer found it in inflammation of the middle ear, but in a case of meningitis following influenza Fraenkel's diplococcus was present. In one or two cases of meningitis, however, the influenza bacillus has been found (Pfuhl and Walter, Cornil and Durante).

Experimental Inoculation.—There is no satisfactory evidence that any of the lower animals suffer from influenza

in natural conditions, and accordingly we cannot look for very definite results from experimental inoculation. Pfeiffer, by injecting living cultures of the organism into the lungs of monkeys, in three cases produced a condition of fever of a remittent type. Somewhat similar results were obtained in one animal by smearing the uninjured mucous membrane of the nose with a pure culture. The fever appeared about twenty-four hours after the injection, and lasted for three to five days. In another case in which large quantities of the bacilli were injected into the trachea, marked prostration and high temperature occurred, death following in twenty-four hours. There was, however, little evidence that the bacilli had undergone multiplication, the symptoms being apparently produced by their toxines. In the case of rabbits, intravenous injection of living cultures produces dyspnœa, muscular weakness, and slight rise of temperature, but the bacilli rapidly disappear in the body, and exactly similar symptoms are produced by injection of cultures killed by the vapour of chloroform. Pfeiffer, therefore, came to the conclusion that the influenza bacilli contain toxic substances which can produce in animals some of the symptoms of the disease, but that animals are not liable to *infection*, the bacilli not having power of multiplying to any extent in their tissues.

Cantani in a recent work succeeded in producing infection to some extent in rabbits, by injecting the bacilli directly into the anterior portion of the brain. In these experiments the organisms spread to the ventricles, and then through the spinal cord by means of the central canal, afterwards infecting the substance of the cord. An acute encephalitis was thus produced, and sometimes a purulent condition in the lateral ventricles. The bacilli were, however, never found in the blood or in other organs. The symptoms produced were great dyspnœa, cardiac weakness, and also a paralytic condition which appeared first in the posterior limbs, and then spread to the rest of the body. The temperature was at first elevated, but before death fell below normal. Similar symptoms were also produced by

injection of dead cultures, though in this case the dose required to be five or six times larger. Cantani therefore concludes that the brain substance is the most suitable nidus for their growth, but agrees with Pfeiffer in believing that the chief symptoms are produced by toxines resident in the bodies of the bacilli. He made control experiments by injecting other organisms, and also by injecting inert substances into the cerebral tissue.

The evidence, accordingly, that the influenza bacillus is the cause of the disease rests chiefly on the well-established fact that it is always present in the secretions of the respiratory tract in true cases of influenza, and that it is an organism which has not been found in any other condition. Moreover, it is an organism which is practically restricted by its conditions of growth to the animal body. A certain amount of confirmatory evidence has been supplied by the results of experiment.

Methods of Examination—(*a*) *Microscopic.*—A portion of the greenish-yellow purulent material which often occurs in little round masses in the sputum should be selected, and film preparations should be made in the usual way. Films are best stained by Ziehl-Neelsen carbol-fuchsin diluted with ten parts of water, the films being stained for ten minutes at least. In sections of the tissues, such as the lungs, the bacilli are best brought out, according to Pfeiffer, by staining with the same solution as above for half an hour. The sections are then placed in alcohol containing a few drops of acetic acid, in which they are dehydrated and slightly decolorised at the same time. They should be allowed to remain till they have a moderately light colour, the time varying according to their appearance. They are then placed in xylol and afterwards mounted in balsam.

(*b*) *Cultures.*—A suitable portion of the greenish-yellow material having been selected from the sputum, it should be washed well in several changes of sterilised water. A portion should then be taken on a platinum needle, and successive strokes made on the surface of blood-agar tubes.

The tubes should then be incubated at 37° C., when the transparent colonies of the influenza bacillus will appear, usually within twenty-four hours.

PLAGUE.

The bacillus of oriental plague or bubonic pest was discovered independently by Kitasato and Yersin during the epidemic at Hong Kong in 1894. The results of their investigations, which were published almost at the same time, agree in all the important points. They cultivated the same organism from a large number of cases of plague, and reproduced the disease in susceptible animals by inoculation of pure cultures. It is to be noted that during an epidemic of plague, sometimes even preceding it, a high mortality has been observed amongst certain animals, especially rats and mice, and that from the bodies of these animals found dead in the plague-stricken district, the same bacillus was obtained by Kitasato and also by Yersin.

FIG 99.—Bacillus of plague from a young culture on agar.
Stained with weak carbol-fuchsin. × 1000.

Bacillus of Plague—*Microscopical Characters.*—As seen in the affected glands or buboes in this disease the bacilli are small oval rods, somewhat shorter than the typhoid bacillus, and about the same thickness (Fig. 99). They have rounded ends, and in stained preparations a portion is sometimes left unstained in the

middle of the bacilli, giving the so-called "pole-staining." In the tissues they are found scattered amongst the cells, for the most part lying singly, though pairs are also seen; but in cultures, especially in fluids, they have a tendency to grow into chains, the form known as a streptobacillus resulting (Fig. 100). Sometimes in the tissues they are seen to be surrounded by an unstained capsule, though this appearance is by no means invariable. They do not form spores, and they are non-motile. They stain readily with the basic aniline stains, but are decolorised by Gram's method.

FIG. 100.—Bacillus of plague in chains showing polar staining. From a young culture in bouillon.
Stained with thionin-blue. × 1000.

Distribution in the Body.—The bacilli have a special relation to the anatomical changes in the tissues. The most striking feature in the disease is the affection of the lymphatic glands, which undergo intense inflammatory swelling, generally ending in a greater or less degree of suppuration if the patient lives long enough. Usually one group of glands is affected first—in the great majority the inguinal or the axillary glands—and afterwards other groups become involved. Along with these changes there is great swelling of the spleen, and often intense cloudy swelling of the cells of kidneys, liver, and other organs. The bacilli occur in enormous numbers in the swollen glands, being so numerous that a film preparation made from a scraping almost resembles a pure culture; they lie irregularly arranged between the cellular elements. In the spleen also they are

fairly numerous, occurring chiefly in small clumps. They occur also in the blood, in which they may be found during life by microscopic examination, chiefly, however, just before death in very severe and rapidly fatal cases. In many cases, however, they cannot be detected in the blood by this means, though in some of these they may be obtained by means of cultures.

Cultivation.—From the affected glands the bacillus can readily be cultivated on the ordinary media. It grows best at the temperature of the body, though growth occurs as low as 18° C. On agar and on blood serum the colonies are circular discs of somewhat transparent appearance and smooth shining surface. When examined with a lens, their borders are slightly wavy. In stroke cultures on agar there forms a continuous line of growth with the same appearance, showing partly separated colonies at its margins. In peptone gelatine, growth takes place along the needle track as a white line, composed of small spherical colonies, whilst on the surface of the gelatine a thin semi-transparent layer is formed, which may spread to the wall of the tube. In bouillon the growth forms a slightly granular or powdery deposit at the foot and sides of the flask, somewhat resembling that of a streptococcus.

In cultures, the organisms present the characters described above, but as the cultures become older a great many swollen and irregular forms are seen.

The organism in its powers of resistance corresponds with other spore-free bacilli, and is readily killed by heat. It resists drying for four days at latest, and exposure to sunlight for three or four hours kills it. When cultivated outside the body the organism rapidly loses its virulence.

Experimental Inoculation.—Rats, mice, guinea-pigs, and rabbits are susceptible to inoculation. After subcutaneous injection there occurs a local inflammatory œdema, which is followed by inflammatory swelling of the lymphatic glands, and thereafter by a general infection. The animals die usually in from one to five days, the chief changes, in addition to the glandular enlargement, being congestion of internal

organs, sometimes with hæmorrhages, and enlargement of the spleen; the bacilli are present in the lymphatic glands and also, though in smaller numbers, throughout the blood. Rats and mice can also be infected by feeding either with pure cultures or with pieces of organs from cases of the disease, and animals infected by inoculation may transmit the disease to healthy animals kept along with them. Kitasato considers that the disease in animals is a close reproduction of the natural disease in the human subject.

There can be no doubt that this bacillus is the immediate cause of the disease, and the bacteriological observations throw much light on its method of spread. The affection of the lower animals by the same bacilli has been abundantly proved, and large numbers of dead animals in the infected localities were found to contain the organism. The disease was produced also by inoculation with dust from infected houses, and Yersin found the organism in large numbers in the bodies of dead flies in the infected locality. The highly insanitary conditions under which the affected individuals live give ample opportunity for the direct or indirect transmission of the disease from patient to patient. Kitasato considers that the bacillus may enter the body by the skin surface through cracks or wounds, by the respiratory passages, or by the alimentary canal. The bacillus was found in the sputum in eleven out of twelve cases of plague examined by Wilm, and in the fæces in several where there were symptoms of enteritis. In connection with an intestinal infection, it may also be mentioned that in some cases where there were no external buboes, a great tumefaction of the mesenteric glands has been found *post mortem*.

Immunity.—Yersin, Calmette, and Borrel succeeded in producing a certain amount of immunity in rabbits against the organism by injection of cultures killed by heat at 58° C. They further found that the serum of such animals had certain protective powers when tested in mice. Later, they immunised a horse by intravenous injection

of the living bacilli, and obtained a serum which had more powerful properties. This anti-plague serum has been employed by Yersin in cases of the disease at Canton, Amoy, and, more recently, Bombay. The reports of the results obtained are of a distinctly favourable character, though not yet sufficiently extensive to supply an accurate estimate of the efficacy of this mode of treatment.

Relapsing Fever.

At a comparatively early date, namely in 1873, when practically nothing was known with regard to the production of disease by bacteria, a highly characteristic organism was discovered in the blood of patients suffering from relapsing fever. This discovery was made by Obermeier, and the organism is usually known as the *spirillum or spirachæte Obermeieri*, or the *spirillum of relapsing fever*. He described its microscopical characters, and found that its presence in the blood had a definite relation to the time of the fever, the organism rapidly disappearing about the time of the crisis, and reappearing when a relapse occurred. He failed to find such an organism in any other disease. His observations were fully confirmed, and his views as to its causal relationship to the disease were generally accepted. Later, the disease was produced in the human subject by inoculations with

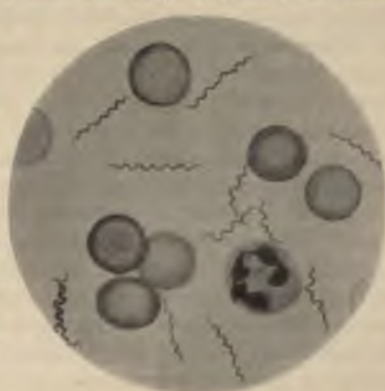

Fig. 101.—Spirilla of relapsing fever in human blood. Film preparation. (After Koch.) × about 1000.

blood containing the organisms, and a similar condition has been produced in apes.

Characters of the Spirillum.—The organisms as seen in the blood during the fever are delicate spiral filaments which have a length of 2 to 6 times the diameter of a red blood corpuscle. They are, however, exceedingly thin, their thickness being much less than that of the cholera spirillum. They show several regular sharp curves or windings, of number varying according to the length of the spirilla, and their extremities are finely pointed (Fig. 101). They are actively motile, and may be seen moving quickly across the microscopic field with a peculiar movement which is partly twisting and partly undulatory, and disturbing the blood corpuscles in their course.

They stain with watery solutions of the basic aniline dyes, though somewhat faintly, and are best coloured in film preparations by Löffler's or Kühne's methylene-blue solutions. When thus stained they usually have a uniform appearance throughout, or may be slightly granular at places, but they show no division into short segments. They lose the stain in Gram's method.

In blood outside the body the organisms have a considerable degree of vitality, and when kept in sealed tubes have been found alive and active after many days. They are readily killed at a temperature of 60° C., but may be exposed to 0° C. without being killed. There is no evidence that they form spores.

Relations to the Disease.—In relapsing fever, after a period of incubation there occurs a rapid rise of temperature which lasts for about five to seven days. At the end of this time a crisis occurs, the temperature falling rapidly to normal. In the course of about seven days another sharp rise of temperature takes place, but on this occasion the fever lasts a shorter time, again suddenly disappearing. A second or even third relapse may occur. The spirilla begin to appear in the blood shortly before the onset of the pyrexia, and during the rise of temperature rapidly increase in number. They are very numerous during the

fever, a large number being often present in every field of the microscope when the blood is examined at this stage. They begin to disappear shortly before the crisis, and after the crisis they are entirely absent from the circulating blood. A similar relation between the presence of the spirilla in the blood and the fever is found in the case of the relapses, whilst between these they are entirely absent. Münch in 1876 produced the disease in the human subject by injecting blood containing the spirilla, and this experiment has been several times repeated with the same result; after a period of incubation the spirilla begin to appear in the circulating blood, and their appearance is soon followed by the occurrence of pyrexia.

Numerous attempts to cultivate this organism outside the body have all been attended with failure, and it has been abundantly shown that it does not grow on any of the media ordinarily in use. Koch found that on blood serum the filaments of the spirilla increased somewhat in length, and formed a sort of felted mass, but that no multiplication took place. Additional proof, however, that the organism is the cause of the disease has been afforded by experiments on monkeys, and facts of considerable interest have been thus established. Carter in 1879 was the first to show that the disease could be readily produced in these animals, and his experiments were confirmed by Koch. In such experiments the blood taken from patients and containing the spirilla was injected subcutaneously. In the disease thus produced there is an incubation period which usually lasts about three days. At the end of that time the spirilla rapidly appear in the blood, and shortly afterwards the temperature quickly rises. The period of pyrexia usually lasts from two to three days, and is followed by a marked crisis. As a rule there is no relapse, but occasionally one of short duration occurs. The presence of spirilla in the blood has the same relation to the pyrexial period as in the human subject.

For a long time the place and mode of destruction of the spirilla were quite unknown, but valuable light was

thrown on these points by Metchnikoff, who produced the disease in monkeys, and killed them at various stages of the fever. He found that during the fever the spirilla were practically never taken up by the leucocytes, but at the time of the crisis the spirilla, on disappearing from the blood, accumulated in the spleen and were ingested in large numbers by the microphages or multi-nucleated leucocytes. Within these they rapidly underwent degeneration and disappeared. Metchnikoff also found that after the spirilla had disappeared from the blood, the disease could be produced in another animal by inoculations with spleen pulp, in which the spirilla were contained within the leucocytes, thus showing that they were living and active in the spleen. It is to be noted in this connection that swelling of the spleen is a very marked feature in relapsing fever. These observations have been entirely confirmed by Soudakewitch, who also showed that the destruction of the spirilla in the spleen was an extremely rapid one, as they were all destroyed ten hours after their disappearance from the blood. He also produced the disease in two monkeys from which the spleen had been previously removed, the animals having been allowed to recover completely from the operation. In these cases the spirilla did not disappear from the blood at the usual time, but rather increased in number, and a fatal result followed on the eighth and ninth days respectively. *Post mortem* he found the spirilla in enormous numbers throughout the blood vessels, and in the portal vein they almost equalled the red blood-corpuscles in number. By these experiments it would appear to be established that the spleen has an important function in the destruction of the organisms. It has not been shown, however, why the organisms disappear from the blood at a particular time and accumulate in the spleen.

In the case of the human subject it has been found that a second attack of the disease can follow the first after a comparatively short period of time, and it is often said that one attack does not confer immunity. It is probably rather the case that the immunity conferred is of very

short duration. The course of events in the disease might be explained by supposing that immunity is produced in the course of the disease, but that it does not last until all the spirilla have been destroyed. With the disappearance of the immunity the organisms reappear in the blood, the relapse being, however, of shorter duration and less severe than the first attack. This is repeated till the immunity lasts long enough to allow all the organisms to be killed. On these points, however, further information is still necessary. Any antimicrobic power which the serum may possess after the crisis has not yet been demonstrated. It is further to be noted that relapsing fever is unique amongst diseases affecting the human subject, in respect of the enormous numbers of organisms which can be observed in the circulating blood during life.

MEASLES.

Though measles is a disease of such frequent occurrence, and though its course and infectiveness suggest the presence of a causal micro-organism, we cannot be said to know definitely anything of the nature of the latter. Two organisms have been stated to be found associated with the disease—one said to be a protozoon, the other a bacillus. With regard to the former, Doehle (in 1892) found in the plasma and red blood-corpuscles, on the first or second day of the disease, more or less numerous round motile organisms $\frac{1}{2}$-1 μ in diameter, with a clear periphery and darker central part. They could be stained by Löffler's methylene-blue. They sometimes showed 2-4 nuclei and one or two flagella. Sometimes they were larger, being 2-2$\frac{1}{2}$ μ in diameter, with a relatively large nucleus which contained 1 to 8 smaller curved bodies. L. Pfeiffer and also Behla have described similar organisms. The latter observed darkly-stained bodies in the nasal mucous membrane, which he looked on as spores. As in the case of other alleged protozoa, these organisms have not been

cultivated, and of their relationship to the disease we can say nothing.

Canon and Pielicke (1892) found, in fourteen cases of measles, bacilli which they look upon as related to the condition. They occurred during the whole course of the disease, in the blood and in the nasal and conjunctival secretion. They could be stained with methylene-blue but not by Gram's method. Growth was obtained only in bouillon. More extended and originally independent observations on apparently the same organism have been made by Czajkowski (1892-95). This observer investigated microscopically fifty-six cases occurring in four epidemics during the years named, and isolated the organism from nineteen of them. He describes the bacilli as varying in length, the shortest being .5 μ long and half that in breadth. The staining reactions were as already noted. They did not grow on ordinary media; but on glycerine agar, especially glycerine blood agar, and on serum, after three to four days at 36°-37° C. growth in the form of transparent colourless colonies was obtained. The organism grew most vigorously in bouillon or in ascitic fluid. Rabbits did not respond to infection, but subcutaneous inoculation in mice was followed by death in from three to four days, with appearances of septicæmia, the bacilli being found in the blood, the spleen, and the liver. With regard to the possible etiological relation of this bacillus to the disease we obviously require more information. We must have further observations as to its invariable occurrence in cases of measles (especially in the nasal secretion, which is probably the material by which infection is conveyed), and also further observations on its pathogenic effect in animals. Here there is the difficulty, that it is questionable whether any of the lower animals are susceptible to human measles. Behla claims to have caused the disease in a sucking-pig by infecting its nasal mucous membrane with the nasal secretion of a child suffering from measles. He states that in the blood of this animal he found the protozoon-like organisms already referred to.

Whatever may be the cause of measles, it depresses the tissues in such a way as to enable other pathogenic organisms to gain an entrance into the body. Such complications as otitis media, broncho-pneumonia, and noma, which not infrequently follow measles, are probably, in the great majority of cases, to be thus explained. From the first two conditions the usual organisms of suppuration and the pneumococcus have been isolated. Noma in similar circumstances probably arises from a variety of organisms the nature of which is as yet little understood.

Rhinoscleroma.

This disease, which properly belongs to the group of infective granulomata, is characterised by the occurrence of chronic nodular thickenings in the skin or mucous membrane of the nose, or in the mucous membrane of the pharynx, larynx, or upper part of the trachea. It is scarcely ever met with in this country, but is of not very uncommon occurrence on the Continent, especially in Austria. In the granulation tissue of the nodules there are to be found numerous round and rather large cells, which have peculiar characters and are often known as the cells of Mikulicz. Their protoplasm contains a collection of somewhat gelatinous material which may fill the cell and push the nucleus to the side. Within these cells there is present a characteristic bacillus, occurring in little clumps or masses which lie chiefly in the gelatinous material. A few bacilli also lie free in the lymphatic spaces around. This organism was first observed by Frisch, and is now known as the bacillus of rhinoscleroma. The bacilli have the form of short oval rods, which, when lying separately, can be seen to possess a distinct capsule, and which in all their microscopical characters correspond closely with Friedländer's pneumobacillus. They are usually present in the lesions in a state of purity. It was at first stated that they could be stained by Gram's method, but more recent observa-

tions show that like Friedländer's organism they lose the stain.

From the affected tissues this bacillus can be easily cultivated by the ordinary methods. In the characters of its growth in the various culture-media it presents a close similarity to that of the pneumobacillus, as it also does in its fermentative action in milk and sugar-containing fluids. The nail-like appearance of the growth on gelatine is said to be less distinct, and the growth on potatoes is more transparent and may show small bubbles of gas; otherwise it resembles the pneumobacillus. It is doubtful whether any distinct line of difference can be drawn between the two organisms so far as their microscopical and cultural characters are concerned.

The evidence that the organisms described are the cause of this disease consists in their constant presence and their special relation to the affected tissues, as already described. From these facts alone it is highly probable that they are the active agents in the production of the lesions. Experimental inoculation has thrown little light on the subject, though one observer has described the production of nodules on the conjunctivæ of guinea-pigs. The relation of the rhinoscleroma organism to that of Friedländer is, however, still a matter of doubt, and the matter has been further complicated by the fact that a bacillus possessing closely similar characters has been found to be very frequently present in ozœna, and is often known as the *bacillus ozœnæ*. The last-mentioned organism is said to have more active fermentative powers. From what has been stated it will be seen that a number of organisms closely allied in their morphological characters, have been found in the nasal cavity in healthy or diseased conditions. From what we know, however, of other diseases, it is not improbable that though presenting these close resemblances, they may be distinct species, and may cause distinct pathological conditions in man. The subject is one on which more light is still required.

CHAPTER XIX.

IMMUNITY.

Introductory.—By immunity is meant non-susceptibility to a given disease or to a given organism under certain conditions, and these conditions may either be such as occur naturally, or may be experimentally produced. The term is also used in relation to the toxines of an organism. Immunity may be possessed by an animal naturally, and is then usually called *natural* immunity, or it may be *acquired* by an animal either by its passing through an attack of the disease occurring under ordinary conditions, or by artificial means of inoculation. We find, for example, that certain diseases affect the lower animals but never occur in the human subject, *e.g.*, swine plague; and, on the other hand, diseases such as typhoid fever and cholera, which are common in the case of the human subject, do not under natural conditions affect any of the lower animals, so far as is known. That is to say, man and the lower animals respectively enjoy immunity against certain diseases, when exposed to infection under ordinary conditions. From this fact, however, it does not follow that when the organisms of the respective diseases are introduced into the body by artificial methods of inoculation, pathological effects will not follow. We have seen above, for example, that the organisms of cholera and typhoid may be made to infect guinea-pigs artificially, though they do not do so under natural conditions. Immunity may thus be of very

varying degrees, and accordingly the use of the term has a correspondingly relative significance. Such a thing as absolute immunity is scarcely known, just as we have seen is the case with absolute susceptibility. This is not only true of infection by bacteria, but in the case of toxines also, when the resistance of an animal to these is of high degree, the resistance may be overcome by a very large dose of the toxic agent. This statement is well illustrated in the case of the great resistance to the toxines of tetanus possessed by the common fowl. This animal may be able to resist as much as 20 c.c. of powerful toxine, but on this amount being exceeded may be affected by tetanic spasms (Klemperer). On the other hand, in cases where the natural powers of resistance are very high, these can be still further exalted by artificial means, that is, the natural immunity may be artificially intensified.

Acquired Immunity in the Human Subject. — The following facts are supplied by a study of the natural diseases which affect the human subject. First, in the case of certain diseases one attack protects against another for many years, sometimes practically for a lifetime, *e.g.*, smallpox, typhoid, scarlet fever, etc. Secondly, in the case of other diseases, *e.g.*, erysipelas, diphtheria, influenza, and pneumonia, a patient may suffer from several attacks. In the case of the diseases of the second group, however, experimental research has shown that in many of them a certain degree of immunity does follow; and, though we cannot definitely state it as a universal law, it must be considered highly probable that the attack of an acute disease produced by an organism, confers immunity for a longer or shorter period.

The facts known regarding vaccination and smallpox exemplify another principle. We may take it as practically proved that vaccinia is variola or smallpox in the cow, and that, when vaccination is performed the patient is inoculated with a modified variola (*vide* Smallpox, in Appendix). Vaccination produces certain pathogenic effects which are of trifling degree as compared with those of smallpox, and

we find that the degree of protection is less complete and lasts a shorter time than that produced by the natural disease. Again, inoculation with lymph from a smallpox pustule produces a form of smallpox less severe than the natural disease but a much more severe condition than that produced by vaccination, and it is found that the degree of protection or immunity resulting occupies an intermediate position. The corresponding general conclusion from experiments is that the more virulent the organism injected, provided that the animal recovers satisfactorily, the higher is the degree of immunity acquired by it against that organism. Thus in developing immunity of the highest degree the most virulent organisms are employed. A corresponding principle, with certain restrictions (*vide* p. 438), obtains in the case of toxines.

Immunity and Recovery from Disease.—Recovery from an acute infective disease shows that in natural conditions the virus may be exhausted after a time, the period of time varying in different diseases. How this is accomplished we do not yet fully know, but it has been found in the case of diphtheria, typhoid, cholera, pneumonia, etc., that in the course of the disease certain substances (called by German writers *Antikörper*) are found to appear in the blood, which are antagonistic either to the toxine or to the vital activity of the organism. In these cases a process of immunisation would appear to be going on during the progress of the disease, and when this immunisation has reached a certain height, the disease naturally comes to an end. It cannot, however, be said at present that such antagonistic substances are developed in all cases, as there are other means by which the spread and multiplication of the organisms may come to be arrested.

Artificial Immunity.

Varieties.—A number of facts regarding immunity have been given in the description of the pathogenic organisms in previous chapters. We shall here give a general systematic

description of the methods, and discuss the principles involved. According to the means by which it is produced, immunity may be said to be of two kinds, to which the terms *active* and *passive* are generally applied, or we may speak of immunity directly, or indirectly, produced.

Active immunity is obtained by (*a*) injections of the organisms either in an attenuated condition or in sub-lethal doses, or (*b*) by sub-lethal doses of their products, *i.e.*, of their "toxines," the word being used in the widest sense. By repeated injections at suitable intervals the dose of organisms or of the products can be gradually increased, and a proportionate degree of resistance or immunity can be developed, which degree in course of time may reach a very high level. In this method a series of reactions is developed within the animal, and this leads to immunity. Such a method can be preventive, but it can never be curative, as the immunity must be developed before the onset of the disease. Immunity of this kind is comparatively slowly produced, and lasts a considerable time, though the period varies in different cases.

Passive immunity depends upon the fact that if an animal be immunised to a very high degree by the previous method, its serum has distinctly antagonistic or neutralising effects when injected into another animal along with the organisms, or with their products, as the case may be. Here the serum of the highly-immunised animal may confer immunity on another animal, if introduced at the same time as infection occurs or even a short time afterwards, and the method can, therefore, be employed as a curative agent. The serum is also preventive, *i.e.*, protects an animal from subsequent infection, but the immunity thus conferred lasts a comparatively short time. These facts form the basis of serum therapeutics.

The method of producing passive immunity was first worked out in the case of tetanus and diphtheria. A high degree of resistance was obtained in certain animals by repeated and gradually-increasing doses of toxine separated by filtration, and it was then found that their serum could

protect other animals from lethal doses of toxine. To such a serum the term *antitoxic* was applied, though the serum protects against the living organisms also. In other diseases a similar method was afterwards employed by injecting the living organisms in gradually-increasing doses, the serum of the animal thus immunised being effective in protecting another animal from infection with the organism. Such a serum is, in the first instance, *antimicrobic*. The relations of the antitoxic to the antimicrobic property will be discussed later, but for facility of description it is advisable to consider them separately.

In the accompanying table a sketch of the chief methods by which an immunity may be artificially produced is given. It has been arranged for purposes of convenience and to aid subsequent description, and it is not to be inferred that all the different methods imply essentially different principles. There is still some doubt as regards the relation of A 2, for example, to A 1 and A 3.

ARTIFICIAL IMMUNITY.

A. Active Immunity—*i.e.*, produced in an animal by an injection, or by a series of injections, of non-lethal doses of an organism or its toxines.

1. *By injection of the living organisms.*

(*a*) Attenuated in various ways. Examples.

(1) By growing in the presence of oxygen, or in a current of air.

(2) By passing through the tissues of one species of animal (becomes attenuated for another species).

(3) By growing at abnormal temperatures, etc.

(4) By growing in the presence of weak antiseptics, or by injecting the latter along with the organism, etc.

(*b*) In a virulent condition, in non-lethal doses.

2. *By injection of the dead organisms.*
3. *By injection of filtered bacterial cultures, i.e. toxines; or of chemical substances derived from these.*

These methods may also be combined in various ways.

B. Passive Immunity, *i.e.*, produced in one animal by injection of the serum of another animal highly immunised by the methods of A.
   1. *By antitoxic serum, i.e.*, the serum of an animal highly immunised against a particular toxine.
   2. *By antimicrobic serum, i.e.*, the serum of an animal highly immunised against a particular organism in the living and virulent condition.

A. *Active Immunity.*

1. **By Living Cultures.**—(*a*) *Attenuated.*—In the earlier work on immunity in the case of anthrax, chicken cholera, swine plague, etc., the methods consisted in the employment of cultures of the living organisms, the virulence of which was so diminished that on inoculation they did not produce a fatal disease, but yet had effects sufficient for protection. The principle is therefore the same as that of vaccination, and the attenuated cultures are often spoken of as vaccines. The virulence of an organism may be diminished in various ways, of which the following examples may be given.

(1) In the first place, practically every organism when cultivated for some time outside the body, loses its virulence, and in the case of some this is very marked indeed, *e.g.*, the pneumococcus. Pasteur found in the case of chicken cholera, that when cultures were kept for a long time in ordinary conditions, they gradually lost their virulence, and that when sub-cultures were made, the diminished virulence persisted. Such attenuated cultures could be used for protective inoculation. He considered the loss of virulence to be due to the action of the oxygen of the air, as he found that in tubes sealed in the absence of oxygen the

virulence was not lost. Haffkine attenuated cultures of the cholera spirillum by growing them in a current of air.

(2) The virulence of an organism for a particular animal may be lessened by passing the organism through the body of another animal. Duguid and Burdon Sanderson found that the virulence of the anthrax bacillus for bovine animals was lessened by being passed through guinea-pigs, the disease produced in the ox by inoculation from the guinea-pig being a non-fatal one. This discovery was confirmed by Greenfield, who found that the bacilli cultivated from guinea-pigs preserved their property in cultures, and could therefore be used for protective inoculation of cattle. He also found that the bacilli became attenuated when grown for successive generations in aqueous humour. A similar principle was applied in the case of swine plague by Pasteur, who found that if the organism producing this disease was inoculated from rabbit to rabbit, its virulence was increased for rabbits but was diminished for pigs. Organisms which had been passed through a series of rabbits produced in the pig illness, but not death, and protection for at least a year resulted. The method of vaccination against smallpox depends upon the same principle.

(3) Many organisms become diminished in virulence when grown at an abnormally high temperature. The method of Pasteur, already described (p. 293), for producing immunity in sheep against anthrax bacilli, depends upon this fact. A virulent organism may also be attenuated by being exposed to an elevated temperature which is insufficient to kill it. Toussaint at an early date obtained protective inoculation against anthrax by means of cultures which had been exposed for a certain time to a temperature of 55° C., though it is possible that in some cases the bacilli were really killed, and immunity resulted from their chemical products.

(4) Still another method may be mentioned, namely, the attenuation of the virulence by growing the organism in the presence of weak antiseptics. Chamberland and Roux, for example, succeeded in attenuating the anthrax bacillus by

growing it in a medium containing carbolic acid in the proportion of 1 : 600. The virulence may also sometimes be attenuated by injecting certain chemical substances along with the bacteria into the body. Iodine terchloride was found by Behring to modify in this way the virulence of the diphtheria bacillus.

These examples will serve to show the principles underlying attenuation of the virulence of an organism. There are, however, still other methods, most of which consist in growing the organism in conditions somewhat unfavourable to its growth, *e.g.*, under compressed air, etc.

(*b*) *By living Virulent Cultures in non-lethal Doses.*—Immunity may also be produced by employing virulent cultures in small, that is, non-lethal doses. In subsequent inoculations the doses may be increased in amount. For example, immunity may thus be obtained in rabbits against the bacillus pyocyaneus. Such a method, however, has had a less wide application, as it has been found more convenient to commence the process by attenuated cultures.

Exaltation of the Virulence.—The converse process to attenuation, *i.e.*, the exaltation of the virulence, is obtained chiefly by the method of cultivating the organism from animal to animal—the method of *passage* discovered by Pasteur (first, we believe, in the case of an organism obtained from the saliva in hydrophobia, though having no causal relationship to that disease). This is most conveniently done by intraperitoneal injections, as there is less risk of contamination. The organisms in the peritoneal fluid may be used for the subsequent injection, or a culture may be made between each inoculation. The virulence of a great number of organisms can be increased in this way, the animals most frequently used being rabbits and guinea-pigs. This method can be applied to the organisms of typhoid, cholera, pneumonia, to streptococci, and staphylococci, and in fact to those organisms generally which invade the tissues.

The virulence of an organism, especially when in a more or less attenuated condition, can also be raised by injecting

along with it a quantity of a culture of another organism either in the living or dead condition. A few examples may be mentioned. An attenuated diphtheria culture may have its virulence raised by being injected into an animal along with the streptococcus pyogenes; an attenuated culture of the bacillus of malignant œdema by being injected with the bacillus prodigiosus; an attenuated streptococcus by being injected with the bacillus coli, etc. A culture of the typhoid bacillus may be increased in virulence, as already stated, by being injected along with a dead culture of the bacillus coli. In such cases the accompanying injection enables the attenuated organism to gain a foothold in the tissues, and it may be stated as a general rule that the virulence of an organism for a particular animal is raised by its growing in the tissues of that animal.

Combination of Methods.—The above methods may be combined in various ways. By repeated injections of cultures at first attenuated and afterwards more virulent, and by increasing the doses, a high degree of immunity may be arrived at.

Anti-Cholera Inoculation.—Haffkine's method for inoculation against cholera exemplifies the above principles. It depends upon (*a*) attenuation of the virus, that is, the cholera organism, and (*b*) exaltation of the virus. The virulence of the organism is diminished by passing a current of sterile air over the surface of the cultures, or by various other methods. The virulence is exalted by the method of *passage*, that is, by growing the organism in the peritoneum in a series of guinea-pigs. By the latter method, its virulence after a time is increased twenty-fold, that is, the fatal dose has been reduced to a twentieth of the original. Cultures treated in this way constitute the *virus exalté*. Subcutaneous injection of the *virus exalté* produces a local necrosis, and may be followed by the death of the animal, but if the animal be treated first with the attenuated virus, the subsequent injection of the *virus exalté* produces only a local œdema. After inoculation first by attenuated and afterwards by exalted virus, the

guinea-pig has acquired a high degree of immunity, and Haffkine believed that this immunity was effective in the case of every method of inoculation, that is, by the mouth as well as by injection into the tissues. After trying his method on the human subject and finding it free from risk, he extended it in practice on a large scale in India in 1894, and these experiments are still going on. So far the results are, on the whole, encouraging. In the human subject two or sometimes three inoculations are made with attenuated virus before the *virus exalté* is used. Wassermann and Pfeiffer, and also Klein, have found, however, that guinea-pigs immunised by Haffkine's method are not immunised against intestinal infection when the animal is treated by Koch's method (that is, by paralysing the intestines with opium, *vide* p. 385). Notwithstanding this fact Haffkine's method may still have a beneficial effect, though it may not be preventive in all cases.

2. **Immunity by Dead Cultures of Bacteria.**—In some cases a high degree of immunity against infection by a given microbe may be developed by repeated and gradually increasing doses of the dead cultures, the cultures being killed sometimes by heat, sometimes by exposure to the vapour of chloroform. Some consider that in this method only the intracellular toxic substances of the organism are introduced when the cultures have been taken from the surface of a solid medium, such as agar, but as the surface is moist, some of the extracellular products must be present also. The cultures when dead produce, of course, less effect than when living, and this method may be conveniently used in the initial stages of active immunisation, to be afterwards followed by injections of the living cultures. The method has been extensively used by Pfeiffer and others in the production of a high degree of immunity in guinea-pigs against the typhoid, cholera, and other organisms.

3. **Immunity by the Separated Bacterial Products or Toxines.**—The organisms in a virulent condition are grown in a fluid medium for a certain time, and the fluid is then

filtered through a Chamberland or other porcelain filter. The filtrate contains the toxines, and it may be used unaltered, or may be reduced in bulk by evaporation, or may be evaporated to dryness. The process of immunisation by the toxine is started by small non-lethal doses of the strong toxine, or by larger doses of toxine the power of which has been weakened by various methods (*vide infra*). Afterwards the doses are gradually increased. Immunity produced in this way is effective not only against the toxine, but also against large doses of the virulent organism in a living condition. This method was carried out with a great degree of success in the case of diphtheria, tetanus, malignant œdema, and other organisms. It appears capable of very general application, though, in the case of some organisms, it is difficult to get a very active toxine from the filtered cultures. It has also been applied in the case of snake poisons by Calmette and Fraser, and a high degree of immunity has been produced.

Immunity may also be obtained by means of certain chemical substances separated from filtered bacterial cultures, though these substances are generally in a more or less impure condition. Hankin was the first to obtain this result by means of an albumose separated from anthrax cultures.

Though, as already stated, none of these methods can be used directly as curative agents, seeing that they imply previous treatment before exposure to infection, yet they supply the means of developing a very high degree of immunity, which is the first stage in the production of an active curative serum.

Immunity by Feeding.—Ehrlich found that mice could be gradually immunised against ricin and abrin by feeding them with increasing quantities of these substances, which are vegetable poisons of enormous potency, and which exhibit an intensely necrotic action at the site of inoculation. In the course of some weeks' treatment in this way the resulting immunity was of so high a degree that the animals could tolerate 400 times the originally fatal dose

by subcutaneous inoculation. Fraser also found in the case of snake poison that rabbits could be immunised by feeding with the poisons, against several times the lethal dose of venom injected into the tissues.

By feeding animals with dead cultures of bacteria or with their separated toxines, a certain degree of immunity may in certain cases be gradually developed. But this method is so much less certain in results, and so much more tedious than the others, that it has obtained no practical applications.

In all the above instances the resulting immunity is specific, that is, is exerted only towards the organism or toxine by means of which it has been produced. A certain degree of immunity or rather of increased general resistance of parts of the body (for example the peritoneum), can, however, be produced by the injection of various substances —bouillon, blood serum, solution of nuclein, etc. (Issaeff). A certain degree of immunity against one organism can also be thus produced by injections of another organism. Immunity of this kind, however, never reaches a high degree, and has not a specific character.

B. *Passive Immunity.*

Action of the Serum of Highly-Immunised Animals.— 1. The serum of an animal A, in which there has been developed a high degree of resistance by repeated and gradually increased doses of the toxine of a particular microbe, protects an animal B against a certain amount of the same toxine when injected along with the latter, or a short time before it. As would be expected, it has less effect when injected some time afterwards, but even then within certain limits, it has a degree of protective or palliative power. As by this method the serum of animal A appears to neutralise the toxine, the term antitoxic has been applied to it. It also protects under like conditions from infection with the corresponding microbe. Thus an anti-diphtheritic serum prepared by injections of

the toxine protects also from injections of the living virulent bacillus.

2. The serum of an animal A, highly immunised against a microbe by repeated and gradually increasing doses of the living organism, protects an animal B against an infection by the living organism when injected under conditions similar to the above. This serum is, therefore, antimicrobic, or preventive against invasion by a particular organism.

In a considerable number of instances, an antimicrobic serum has been found to possess little effect against the toxine—that is, to possess little or no antitoxic power. This fact, if taken alone, would leave it still doubtful whether the difference between the two kinds of sera were one of quality or one merely of quantity.

It has, however, been shown in many cases that antimicrobic sera have a distinct action on the vital activity of the corresponding bacterium, an action which may, in most instances, be called *indirectly bactericidal.* It is manifest that such an action differs fundamentally in its nature from the power of protecting against a toxine. It must not be supposed, however, that a serum must be purely antitoxic or purely antimicrobic, according to the method by which it is prepared. For example, an antitoxic serum can readily be obtained by injecting living diphtheria bacilli into the tissues of an animal, the antitoxic property being in all probability developed by means of toxines formed by the bacilli within the body. Having given this explanation, we shall describe the modes of preparation of the two kinds of serum and discuss their properties separately.

1. **Antitoxic Serum.**—The best examples are the antitoxic sera of diphtheria and tetanus, though similar principles and methods are involved in the preparation of the sera protective against ricin and abrin, and against snake poison. We shall here speak of diphtheria and tetanus. The steps in the process of preparation may be said to be the following: First, the preparation of a powerful toxine.

Second, the estimation of the power of the toxine. Third, the gradual development of a high degree of resistance in a suitable animal by gradually increasing doses of the toxine. Fourth, the estimation from time to time of the antitoxic power of the serum of the animal thus treated.

1. *Preparation of the Toxine.*—This implies selection of a virulent culture, and also growing it in conditions suitable for the highest development of toxine. In the case of diphtheria a virulent culture (its power having been previously tested by inoculation in guinea-pigs) is grown in large vessels containing bouillon in a comparatively thin layer. Some authorities consider that the highest development of toxine takes place when a current of sterile moist air is made to pass over the surface of the medium. This can be readily done by having two apertures in the vessel, one of which is connected with a tube leading to a water-exhaust apparatus. The air, which enters by the other aperture, is first made to pass through a vessel of water and then through a glass tube plugged with sterile cotton wool. In this way a constant current of air may be maintained. The air ought to pass slowly through the vessels, and its rate may be regulated by having a screw-clip on the exit tube. Some observers, however, find that an equally powerful toxine is produced without this arrangement for aëration, if the culture is made to grow as a pellicle on the surface of the bouillon, in which case the growth should not be disturbed till the toxine is fully formed. In order that a powerful toxine may be formed, it is essential that the bouillon be practically free from glucose. After the maximum toxicity is reached, usually in three or four weeks, the culture is filtered through a Chamberland filter. Instead of bouillon, fluid blood serum of the ox or horse may be used, in which the toxine is said to form more quickly. The process of filtration of serum, however, is more difficult. Mixtures of bouillon and serum are also employed.

In the case of tetanus, the growth takes place in glucose bouillon under an atmosphere of hydrogen (*vide* p. 67), and the culture is afterwards filtered in the same manner.

2. *Estimation of the Toxine.*—The power of the toxine is estimated by the injection of varying amounts in a number of guinea-pigs, and the minimum dose which will produce death within forty-eight hours is thus obtained. In the case of diphtheria, a powerful toxine is one of which 1 c.c. subcutaneously injected kills a guinea-pig within forty-eight hours, though toxines may be prepared of which .02 c.c. may have this effect. In the case of tetanus, toxicity of such a degree may be reached that a dose of $\frac{1}{100}$ c.c. will kill a guinea-pig. It is to be noted that the fatal dose of course varies with the body weight of the animal. As a matter of convenience, guinea-pigs of about 250 grms. are usually employed.

3. *Immunisation by means of the Toxine.*—The earlier experiments on tetanus and diphtheria were performed on the small animals, such as guinea-pigs, but afterwards the sheep and the goat were used, and finally horses. In the case of the small animals, it was found advisable to use in the first stages of the process either a weak toxine or a powerful toxine modified by certain methods. Such methods are the addition to the toxine of terchloride of iodine (Behring and Kitasato), the addition of Gram's iodine solution in the proportion of one to three (Roux and Vaillard), and the plan, adopted by Vaillard in the case of tetanus, of using a series of toxines weakened to varying degrees by being exposed to different temperatures, viz. 60°, 55°, and 50° C. But in the case of large animals, such as the horse, the first injections are simply made with small doses of the ordinary toxine. The toxine is at first injected into the subcutaneous tissues, the dose being gradually increased according to the results of the toxine injected. As pointed out by Behring, immunisation proceeds best when each injection produces a reaction in the form of localised inflammatory swelling; in other words, the dose should be as large as possible, so long as general injurious effects are not produced. It was found by Roux that the number of injections also affected the result, a higher degree of immunity being obtained by several small doses than by the same quantity of toxine in

a single large dose. Later, when large doses of toxine injected subcutaneously are well borne, the toxine is injected directly into the jugular vein of the animal. Ultimately 300 c.c., or more, of active diphtheria toxine thus injected may be borne by a horse, such a degree of resistance being developed after the treatment has been carried out for two or three months. In all cases of immunising, the general health of the animal ought not to suffer. If the process is pushed too rapidly, the antitoxic power of the serum may diminish instead of increasing and a condition of marasmus may set in and may even lead to the death of the animal. (In immunisation of small animals an indication of their general condition may be obtained by weighing them from time to time.)

Up till recently, the preparation from a horse of an antitoxic serum of high value involved very prolonged treatment, usually lasting for eight or ten months. Cartwright Wood has, however, devised a method by which the period of immunisation is much shortened, and which promises to give serum of very high antitoxic powers. In this method he uses two "toxines." The one is the ordinary toxine obtained from bouillon cultures as above described, which is believed to contain the ferments; the other is obtained by growing the diphtheria bacillus in a mixture of bouillon and 20 per cent of blood serum (the latter is prevented from coagulating by having its lime salts precipitated by oxalic or citric acid). Such a culture when filtered contains the ferments along with a large proportion of albumoses, produced by the action of the bacillus on the albumin. The ferments are destroyed by exposure to 65° C. for an hour, and the fluid is then known as "serum toxine" in contra-distinction to the ordinary "broth toxine." The serum toxine gives rise to little local irritation but to marked febrile reaction. By its use the early period of immunisation is much shortened, so that a horse can tolerate a large dose of ordinary broth toxine in a shorter time than was formerly possible; and by combining its use with that of broth toxine a serum of remarkably high antitoxic powers

may be obtained in a month or two. In one case the serum obtained by Wood reached the value of 1000 units per c.c. (*vide infra*).

4. *Estimating the Antitoxic Power of, or "standardising," the Serum.*—This is done by testing the effect of various quantities of the serum of the immunised animal against a certain amount of toxine, conveniently ten times the lethal dose, *e.g.*, 1 c.c. of toxine, of which .1 c.c. is the lethal dose. Various standards have been used, of which the two chief are that of Behring and Ehrlich and that of Roux. Behring adopts as the *unit of immunity* 1 c.c. of a serum of which .1 c.c. *protects completely*[1] from ten times the lethal dose of toxine, the serum and toxine being mixed and injected together. For example, 1 c.c. of a serum of which .002 c.c. will protect from ten times the lethal dose, will possess fifty immunity units, and 20 c.c. of this serum 1000 immunity units. Serum has been prepared of which 1 c.c. has the value of 600 units or even more.

Roux adopts a standard which represents the animal weight protected by 1 c.c. of serum against the lethal dose of virulent bacilli, the serum being injected twelve hours previously. Thus, if .01 c.c. of a serum will protect a guinea-pig of 500 grms. against the lethal dose, 1 c.c. (1 grm.) will protect 50,000 grms. of guinea-pig, and the value of the serum will be 50,000.

During the process of immunisation of an animal against the toxine, a small quantity of its blood is withdrawn from time to time, and the antitoxic power tested in the manner described above. After a sufficiently high degree of antitoxic power has been reached, the animal is bled under aseptic precautions, and the serum is allowed to separate in the usual manner. It is then ready for use, but some weak antiseptic such as .5 per cent carbolic acid is usually added to prevent its decomposing. Other antitoxic sera are prepared in a corresponding manner.

[1] By this is meant not only that a fatal result does not follow, but also that there is an absence of local swelling.

Some further facts about anti-tetanic serum are given on page 365.

Use of Antitoxic Sera.—In all cases the antitoxic serum ought to be injected as early in the disease as possible, and in large doses. In the case of diphtheria 1500 immunity units of antitoxic serum was the amount first recommended for the treatment of a bad case, but the advisability of using larger doses has gradually become more and more evident. Sidney Martin recommends that as much as 4000 units should be administered at once, and that if necessary this quantity should be repeated. The strongest serum prepared at present by Behring contains 3000 units in 5-6 c.c., but, as already stated, there is now a good prospect of obtaining a more powerful serum easily. Even very large doses of antitoxic serum are without any harmful effects beyond the occasional production of urticarial and erythematous rashes. Where large quantities of serum require to be administered, as is always the case with anti-tetanic serum, injections must be made at different parts of the body; preferably not more than 20 c.c. should be injected at one place. The immunity conferred by injection of antitoxic serum lasts a comparatively short time, usually a few weeks at longest.

Sera of Animals immunised against Vegetable and Animal Poisons.—It was found by Ehrlich in the case of the vegetable toxines, ricin and abrin, and also by Calmette and Fraser in the case of the snake poisons, that the serum of animals immunised against these respective substances had a protective effect when injected along with them into other animals. Ehrlich found, for example, that the serum of a mouse which had been highly immunised against ricin by feeding as described above, could protect another mouse against forty times the fatal dose of that substance. He considered that in the case of the two poisons, antagonistic substances—"anti-ricin" and "anti-abrin"—were developed in the blood of the highly-immunised animals. A corresponding antagonistic body, to which Fraser has given the name anti-venin, appears in the blood of animals in the process of immunisation against snake-poison.

These investigations are specially instructive, as the poisons, both as regards their local action and the general toxic phenomena produced by them, present an analogy to various toxines of bacteria.

Action of Antitoxic Serum.—In order to protect an animal from the toxine, the antitoxic serum must be added in a definite proportion. It has no cumulative action, or in other words, it cannot neutralise a larger amount of toxine simply by being left in contact with it for a longer period of time. Experiment shows that there is an antagonistic action between the toxine and the antitoxine, but the nature of this action is not yet fully known. We know almost certainly that the action is not a simple chemical one comparable with the action of base and acid, but that vital processes are involved, so that we may call the antagonism a physiological one. For example, it was found by Roux and Vaillard that if too large doses of the toxine were administered in immunising a horse, the blood serum might lose its antitoxic power and actually become toxic for another animal. Buchner found that a mixture of antitoxine and toxine could be prepared so as to be practically harmless for mice, but have a toxic action for guinea-pigs. In this connection, however, it must be borne in mind that the natural resistance of the guinea-pig against tetanus toxine is less than that of the mouse, and that antitoxine as well as toxine has a relative value. The antitoxine in all probability acts on the tissues susceptible to the toxine and makes them immune to the toxine, or toxine-proof, but we can say little further than this. It has been found that immunity lasts for some time after the antitoxine has disappeared from the blood. The very small amount of antitoxine which is, in some cases, sufficient to protect from a proportionately large dose of toxine, shows the action to be of a very subtle nature. A serum may have high antitoxic power without possessing any bactericidal action against the corresponding bacterium. The diphtheria and tetanus bacilli, for example, flourish well in their respective anti-sera. The fact that these sera

protect an animal against the living organisms has already been explained. We know little regarding the mode and seat of formation of the antitoxines, though they are, doubtless, the products of cellular activity induced by the toxine. It has been shown that a horse, after its serum has reached a high antitoxic power, may be repeatedly bled and the serum still maintain this power little diminished, though no more toxine has been injected. In this case it would appear that the formation of antitoxine continued after the stimulus supplied by the toxine had been removed.

Antitoxine, when present in the serum, leaves the body by the various secretions, and in these it has been found though in much less concentration than in the blood. It is present in the milk, and a certain degree of immunity can be conferred on animals by feeding them with such milk, as has been shown by Ehrlich, Klemperer, and others. Klemperer also found traces of antitoxine in the yolk of eggs of hens whose serum contained antitoxine.

2. **Antimicrobic Serum.**—We have already stated that an antitoxic serum, so far as is known, also protects from an *invasion* of the corresponding organism, though it has no actually bactericidal properties. In such a case the toxines of the organisms are rendered non-effective by the antitoxic serum, and the organisms themselves may then be destroyed by the means normally possessed by the tissues. A serum which protects in a high degree from such microbic invasion can, however, be obtained also by injection of gradually increasing doses of living cultures. A serum prepared by the latter method has often little or no antitoxic power, and appears to exercise its beneficial effect by leading indirectly to the death of the organisms. Hence it is called *antimicrobic*.

The stages in preparation of antimicrobic sera correspond to those in the case of antitoxic sera, but living, or, in the early stages, dead cultures are used instead of the toxine separated by filtration, and in order to obtain a serum of high antimicrobic power, a very virulent culture

in large doses must be ultimately tolerated by the animal. For this purpose a fairly virulent culture is obtained fresh from a case of the particular disease, and its virulence may be further increased by the method of *passage*. This method of obtaining a high degree of immunity against the microbe is specially applicable in the case of those organisms which invade the tissues and multiply to a great extent within the body, and of which the toxic effects, though always existent, are proportionately small in relation to the number of organisms present. The method has been applied in the case of the typhoid and cholera organisms, the bacillus of bubonic plague, the bacillus coli communis, the pneumococcus, streptococcus (Marmorek), and many others. In fact, it seems capable of very general application.

The important result obtained by such experiments is, that if an animal be highly immunised by the method mentioned, the development of the immunity is accompanied by the appearance in the blood of protective substances, which can be transferred to another animal. The law enunciated by Behring regarding immunity against toxines thus holds good in the case of the living organisms, as was first shown by Pfeiffer. The latter found, for example, that in the case of the cholera organism, so high a degree of immunity could be produced in the guinea-pig, that .002 c.c. of its serum would protect another guinea-pig against ten times the lethal dose of the organisms, when injected along with them. Here again is presented the remarkable potency of the antagonising substances in the serum, which in this case lead to the destruction of the corresponding microbe.

The *anti-streptococcic serum* of Marmorek may be briefly described, as it has come into extensive practical use. This observer found that he could intensify the virulence of a streptococcus by growing it alternately in the peritoneal cavity of a guinea-pig, and in a mixture of human blood serum and bouillon (*vide* p. 155). The virulence became so enormously increased by this method that when only

one or two organisms were introduced into the tissues of a rabbit, a rapidly fatal septicæmia was produced. Streptococci of this high degree of virulence were used first by subcutaneous, afterwards by intravenous injection, to develop a high degree of resistance in the horse. Injections were continued over a considerable period of time, and the protective power of the serum was tested by mixing it with a certain dose of the virulent organisms, and then injecting into a rabbit. The serum of a horse highly immunised in this way constitutes the anti-streptococcic serum, which has been extensively used with success in many cases of streptococcic invasion in the human subject. Marmorek, however, found that this serum had little antitoxic power, that is, could only protect from a comparatively small dose of toxine obtained by filtration of cultures.

Anti-typhoid, anti-cholera,[1] anti-pneumococcic, anti-plague, and other sera are all prepared in an analogous manner.

Properties of Antimicrobic Serum. Pfeiffer's Phenomenon and its Modifications. — Within the last two or three years a number of important reactions presented by antimicrobic serum against the corresponding organism, have been discovered, and these are of high importance, as they afford valuable aid in the study of the nature of the preventive power.

Pfeiffer found that if cholera organisms were injected into the peritoneal cavity of a guinea-pig highly immunised against the organism, these lost their motility almost immediately, gradually became granular and swollen up in places into droplets, and then disappeared in the fluid, all these changes sometimes occurring within half an hour. Further, he found that the same phenomenon was witnessed if a minute quantity of anti-cholera serum (that is, the serum of an animal highly immunised against the cholera organism) was added to a certain quantity of cholera microbes, and then injected into the peritoneal

[1] A true *antitoxic* cholera serum has been prepared by Metchnikoff, E. Roux, and Taurelli-Salimbini.

cavity of another animal. In this case the organisms die an extracellular death, and their destruction is brought about by the medium of a specific substance in the anti-cholera serum. Pfeiffer found that the serum of convalescent cholera patients gave the same reaction as that of immunised animals, that is, it possesses specific antagonising substances. He obtained the same reaction also in the case of the typhoid bacillus and other organisms. From his observations he concluded that the reaction was specific and could be used as a means of distinguishing organisms which resemble one another.

The specific property is still possessed by the serum when heated to 60° C., a temperature which rapidly destroys all ordinary bactericidal power. Pfeiffer considered that the specific substance in the serum existed chiefly in an inert form, and that it became actively bactericidal[1] by the aid of living cells, probably those of the peritoneal endothelium. He found that if the anti-serum was injected into the peritoneal cavity of a fresh animal, and if, after a time, some of the peritoneal fluid was withdrawn and the corresponding organism added to it, the reaction could be observed outside the body. Metchnikoff, however, showed that the same result was obtained when the organism was simply placed in some fresh peritoneal fluid to which the anti-serum had been added outside the body. In this case the action of the endothelial cells was excluded, and Metchnikoff concluded that the reaction was due to substances derived from the breaking down of leucocytes (these being the only cells in the peritoneal fluid) by the action of the specific substance in the anti-serum.

This observation of Metchnikoff was confirmed by Bordet, who further improved the method of observing the reaction outside the body, as follows: (*a*) an emulsion of the living organisms (for example of the cholera vibrio) was made by adding a young culture to about 5 c.c. of bouillon; (*b*) two drops of this emulsion were taken, and mixed with

[1] In some cases an antimicrobic serum possesses specific *directly* bactericidal powers, but this is not the general rule.

a small drop of anti-cholera serum; (*c*) a drop of this mixture was taken, and there was added to it a drop of equal size of fresh serum from a normal guinea-pig. A hanging-drop preparation was made, and a change similar to that described by Pfeiffer was observed within one to two hours if the preparation was kept at the temperature of the body. He found that in every case in which Pfeiffer's reaction took place within the body of an animal, a similar reaction could be observed by his method outside the body. He considers that the reaction depends upon the presence of a specific immunising substance in the anti-serum which greatly increases the bactericidal power of the normal serum, but that in most cases this specific substance cannot lead to the destruction of the organisms without the aid of healthy serum. Bordet holds that the source of the protective substance as well as that of bactericidal substances is in the leucocytes.

Charrin and Roger had previously (1889) observed that when the bacillus pyocyaneus was grown in the serum of an animal immunised against this organism, the growth formed a deposit at the foot of the vessel; whereas a growth in normal serum produced a uniform turbidity. Gruber and Durham, in investigating Pfeiffer's reaction, discovered a somewhat analogous phenomenon. They found that when a small quantity of the serum of an animal highly immunised against a particular motile organism (cholera vibrio, typhoid bacillus, etc.) is added to an emulsion of the organisms, the latter lose their motility, and become agglomerated into clumps. In a small test-tube a reaction in this way occurs which is visible to the naked eye, a sort of precipitate forming which consists of masses of non-motile organisms. The higher the degree of immunity, the smaller is the amount of serum necessary to bring about this phenomenon. The serum, therefore, has a sort of paralysing action against the organism, which is manifested outside the body, and which Durham considers forms the essential part of Pfeiffer's reaction. When the organisms are thus weakened by the specific serum within the peri-

toneum, the normal bactericidal power of the peritoneal fluid comes into action and completes the process. It would be fruitless to discuss the nature of these reactions in greater detail, as many of the important points are still *sub judice*. It is sufficient to point out the dual character of the process involved in the action of these antimicrobic sera, and the fact that they contain substances which in very minute doses become effective against the corresponding organisms.

The observations just described are of great importance in relation to the nature of acquired immunity, and further, they have led to the discovery of the method of serum diagnosis of disease, which has been applied especially to typhoid fever, as already detailed (*vide* p. 322). It had been already found that the serum of convalescents from typhoid fever could protect animals to a certain extent against typhoid fever, and, in view of the facts experimentally established, it appeared a natural proceeding to inquire whether such serum possessed an agglomerating action and at what stage of the disease it appeared. The result, obtained first by Widal, was to show that the serum possessed this specific action long before the cure of the disease, in fact shortly after infection had taken place. A process of immunisation accordingly appears to be progressing from an early stage of the disease. It has also been shown recently by M'Fadyean, and also by Delépine, that the glanders bacillus, which of course is a non-motile organism, becomes agglomerated by the serum of animals suffering from glanders. Bordet has found that on the contrary, anti-streptococcic serum has no such action on a streptococcus. The nature of this agglomerating action is not yet fully understood.

Summary with regard to Anti-Sera.—In a former chapter it has been shown that in the production of disease by bacteria there are two main factors concerned, viz., the multiplication of the living organisms in the tissues and the production by them of toxines. The facts which have been stated above show that in the blood serum of highly immunised animals there are present substances of remark-

able potency, which may act against either of these two factors. In the first place, a serum may protect against the separated toxine, or, in other words, may be antitoxic. In this case there is immunity also against the living organisms, as might naturally be expected; for when their toxines are neutralised their harmful action on the tissues is removed, and they are then destroyed probably by the same means as ordinary non-pathogenic organisms. In the second place, a serum may lead to the destruction of the organisms. In this case, it is usually indirectly bactericidal, *i.e.*, becomes bactericidal in certain conditions, though in many instances a directly paralysing action on the organisms has also been demonstrated. The term antimicrobic is, therefore, conveniently applied to such a serum. In many instances an antimicrobic serum has little or no effect against the toxines; this is the case with the anti-streptococcic serum (Marmorek), the anti-cholera and anti-typhoid sera (Pfeiffer), and many others. The action of both varieties of anti-sera, so far as is known, is specific, being exerted only against the particular organism or toxine by the action of which the immunity has been produced. In the case of both, immunity can be transferred to another animal by means of a certain quantity of the serum, the latter having a definite value which can be ascertained by experiment. It does not follow from what has been said that a serum may not act in both of the ways described. A given serum might, for example, be powerfully antimicrobic and feebly antitoxic at the same time, and even a single chemical substance might conceivably have both effects. Nevertheless the two modes of action are distinct.

Theories as to Acquired Immunity.

The advances made within recent years in our knowledge regarding artificial immunity and the methods by which it may be produced have demonstrated the insufficiency of various theories which had been propounded.

They also show the futility of attempting, even now, to make a general statement which would be applicable to all cases. One or two of these theories may, however, be mentioned, as they are of interest in connection with the development of this subject.

1. *The Theory of Exhaustion*, with which Pasteur's name is associated, supposes that in the body of the living animal there are substances necessary for the existence of a particular organism, which become used up during the sojourn of that organism in the tissues; this pabulum being exhausted, the organisms die out. Such a supposition is, of course, quite disproved by the fact of passive immunity, as a small quantity of serum in which the pabulum has been exhausted cannot lead to its exhaustion in the serum of another animal.

2. *The Theory of Retention* supposes that the organisms within the body produce substances which are inimical to their growth, so that they die out, just as they do in a test-tube culture before the medium is really exhausted. In its simple form, the theory is scarcely tenable, as it would be difficult to conceive how such substances could be retained in the body for so many years as acquired immunity sometimes lasts. In a modified form, however, it might include theories still held and which are founded on the facts of passive immunity. It might, for example, include the theory of Buchner, according to which the antitoxic substance in the serum is merely a modified toxine, which has the power of producing in another animal a rapid reaction resulting in immunity. The facts stated above with regard to the production of antitoxine are, however, quite opposed to such a supposition.

3. *The Theory of Phagocytosis.*—This is the theory which was brought forward by Metchnikoff to explain the facts of natural and acquired immunity, and which has been of enormous influence in stimulating research on this subject. Looking at the subject from the standpoint of the comparative anatomist, he saw that it was a very general property possessed by certain cells throughout the animal

kingdom that they should take up foreign bodies into their interior and in many cases destroy them. On extending his observations to what occurred in disease, he came to the conclusion that the successful resistance of an animal against bacteria depended on the activity of certain cells called phagocytes. In the human subject he distinguished two chief varieties, namely (*a*) the microphages, which are the multinucleated leucocytes of the blood, or more correctly, those with multipartite nucleus; and (*b*) the macrophages, which include the larger uninucleated leucocytes, endothelial cells, connective tissue corpuscles, and, in short, any of the larger cells which have the power of ingesting bacteria. Insusceptibility to a given disease is indicated by a great activity on the part of the phagocytes, different varieties being concerned in different cases,—an activity which may rapidly destroy the bacteria and prevent even local damage. If the animal is moderately susceptible and the organisms are introduced into the subcutaneous tissue, there occurs an inflammatory reaction with local leucocytosis, which results in the intracellular destruction of the invading organisms. Phagocytosis is regarded by Metchnikoff as the essence of inflammation. He also showed that the bacteria may be in a living and active state when they are ingested by leucocytes. On the other hand, he found that in a susceptible animal phagocytosis did not occur or was only imperfect. He also found that when a naturally susceptible animal was immunised, the process was accompanied by the appearance of an active phagocytosis. The leucocytes and other cells are guided in their attack on the organisms by chemiotaxis, a process which has already been explained. According to this theory, in the process of immunisation by attenuated cultures the phagocytes are so educated by dealing with the bacteria in an attenuated condition that they can ultimately destroy them even in a highly virulent state.

The work of Metchnikoff has been of great importance in demonstrating one of the chief means possessed by the body of dealing with invading organisms, and for a time his theory obtained considerable support as an explanation of

the facts of immunity. The insufficiency of the theory, however, was at once apparent when the method of immunising against a toxine was discovered; and the facts discovered later, with regard to the action of antimicrobic sera, showed that the cellular ingestion of bacteria was not the most important factor in immunity against the living organisms. The theory as originally propounded is, accordingly, no longer tenable, and even if it were consistent with facts it only removes the property of immunity a step farther back, namely, to the phagocytes. The phenomena of phagocytosis so admirably demonstrated by Metchnikoff may be regarded as the results of immunity, but cannot be accepted as its cause.

4. *The Humoral Theory.*—This theory, which ascribed immunity to changes in the serum and other fluids of the body, was chiefly developed by Behring and by others of the German school. It may be said to have originated with the discovery of bactericidal power possessed by normal blood serum; and the earlier work consisted in an attempt to explain natural and acquired immunity by supposing changes to take place in this bactericidal power. It is, however, unnecessary to state the various phases through which the theory has passed, as these are now chiefly of historic interest. So far as active immunity is concerned, it may be held as proved that certainly the appearance of immunity is accompanied by changes in the serum, as described above, that is, by the development of antimicrobic or antitoxic substances. No doubt, however, such substances are not produced simply by chemical changes in the body fluids, but are products of cellular action brought about by the presence of the bacteria or their toxines. The question remains as to which cells chiefly generate such substances. A considerable amount of evidence, which it is unnecessary to detail, has been brought forward by Metchnikoff, Bordet and others to show that both bactericidal substances and the indirectly bactericidal substances of antimicrobic sera, are derived from leucocytes. In this way the theory of

phagocytosis has undergone modification. Similar evidence with regard to the origin of antitoxic substances is wanting. The whole question, however, is still an open one, and the formation of all these bodies may not be restricted to one class of cells, but may take place more generally.

Natural Immunity.

We have placed the consideration of this subject after that of acquired immunity, as the latter supplies facts which indicate in what direction an explanation of the former may be looked for. There may be said to be two main facts with regard to natural immunity. The first is, that there is a large number of bacteria—the so-called non-pathogenic organisms—which are practically incapable, unless perhaps in very large doses, of producing pathogenic effects in any animal; when these are introduced into the body, they rapidly die out. This fact accordingly shows that the animal tissues generally have a remarkable power of destroying living bacteria. The second fact is, that there are other bacteria which are very virulent to some species of animals, whilst they are almost harmless to other species; the anthrax bacillus may be taken as an example. Now it is manifest that natural immunity against such an organism might be due to a special power possessed by an animal of destroying the organisms when introduced into its tissues. It might also, however, be due to an insusceptibility to, or power of neutralising, the toxines of the organism. For the study of the various diseases shows that the toxines (in the widest sense) are the weapons by which morbid changes are produced, and that toxine-formation is a property common to all pathogenic bacteria. No doubt, as we have seen, the power of toxine production does not go hand in hand with the power of multiplying throughout the body. In the case of organisms which multiply in the blood and produce septicæmia, the amount of toxine formed relatively to the number of the organisms is small, and it would appear as if these

organisms had especially a power of destroying the normal preventive power resident in the blood and tissues. There is, however, no such thing known as an organism multiplying in the living tissues without producing local or general changes, though, theoretically, there might be. We may infer from this that if the toxines are completely neutralised or rendered powerless in the case of any animal, that animal will be immune against the particular organism. This is also borne out by the fact that immunity against a particular organism can be artificially obtained by injections of the toxines of that organism.

(*a*) *Variations in Natural Susceptibility to Toxines.*—We may consider, then, the question in the first instance from the point of view of toxines. Now we must start with the fundamental fact, incapable of explanation, that toxicity is a relative thing, or in other words that different animals have different degrees of resistance or non-susceptibility to toxic bodies. In every case a certain dose must be reached before effects can be observed, and up to that point the animal has resistance. This natural resistance is found to present very remarkable degrees of variation in different animals. The great resistance of the common fowl to the toxine of the tetanus bacillus may be here mentioned; the high resistance of the pigeon to morphia is a striking example in the case of vegetable poisons. This variation in resistance to toxines applies also to those which produce local effects, as well as to those which cause symptoms of general poisoning. Instances of this are furnished, for example, by the vegetable poisons ricin and abrin, by the snake poisons, and by bacterial toxines such as that of diphtheria. We must take this natural resistance for granted, and there is no evidence that for each case there is an antitoxic body which protects till the poisonous dose is reached. The serum of the fowl does not protect a susceptible animal from the tetanus toxine, though the serum of a naturally less susceptible animal in which a resistance equal to that of the fowl has been artificially developed, does possess antitoxic powers. The resistance

or non-susceptibility of the fowl to the tetanus poison evidently resides in the tissues, and it has not been shown that in them antitoxic substances are present, though the possibility of this has not been excluded in all cases. It is possible then that an animal might be immune against the anthrax bacillus, for example, if the toxines of the latter were simply inert towards the animal tissues, or, in other words, if its tissues enjoyed a natural insusceptibility to the toxines. In such a case the anthrax bacillus would be in the position of the bacillus subtilis, and would be destroyed in the tissues by the same means.

(*b*) *Natural Bactericidal Powers.*—The second factor may now be considered, namely, the power of killing the organism, though it appears to us that natural immunity has been too exclusively looked at from this side. Special powers of destroying organisms in natural immunity have been ascribed to (*a*) phagocytosis, and (*b*) the action of the serum.

(*a*) The chief factors with regard to phagocytosis have been given above. The bacteria in a naturally immune animal, for example, the anthrax bacillus in the tissues of the white rat, are undoubtedly taken up in large numbers by the phagocytes, whereas in a susceptible animal this only occurs to a small extent; and Metchnikoff has shown that they are taken up in a living condition, and are still virulent when tested in a susceptible animal. But is this phagocytosis the cause or the effect of immunity? The fact of artificial immunity would rather point to its being the latter. The following experiment performed by Metchnikoff, though belonging to the subject of artificial immunity, may be given here. He injected into a guinea-pig a virulent culture of the bacillus of hog-cholera, and at the same time injected the antiserum of the same organism into a vein. At the end of a few hours a local swelling formed at the site of injection, in which there were enormous numbers of bacilli but no leucocytes. After another injection of the serum, however, the leucocytes gathered around and attacked the bacilli. From this experiment he infers that the serum

introduced a hyperactivity of phagocytes. The matter, however, may be interpreted from another point of view, namely, that it was not until the toxines of the bacilli were neutralised, or at least till the bacilli were weakened by the action of the serum, that the phagocytes could attack them. All the striking phenomena of phagocytic action in the case of natural immunity can be looked at from the latter point of view, and it appears to us that the evidence of the essence of natural immunity depending upon special properties of the phagocytes, is quite insufficient. If such was really the case, these special properties of the phagocytes would demand the same explanation as natural immunity of the individual. While it must be recognised, therefore, that in phagocytic action the body possesses a powerful means of destroying harmless, and, to a certain extent, harmful organisms, and that it is one of the important means by which the bacterium-free condition of the body is maintained, the facts of natural, just as of acquired, immunity must have another explanation.

(*b*) When it had been shown that normal serum possessed certain bactericidal powers against different organisms, the question naturally arose as to whether this bactericidal power varied in different animals in proportion to the natural immunity enjoyed by them. The earlier experiments of Behring appeared to give grounds for the belief that this was the case. He found, for example, that the serum of the white rat, which has a remarkable immunity to anthrax, had greater bactericidal powers than that of other animals investigated. He found also that the serum of guinea-pigs immunised against the vibrio Metchnikovi had a bactericidal action, whereas in that of susceptible animals no such action was found. Further investigation, however, has shown that these are not examples of a general law, and that this bactericidal action of the serum does not vary *pari passu* with immunity either in the natural condition or when artificially produced. The bactericidal action of the serum was specially studied by Buchner and Hankin, who believe that the serum owes

its power to certain substances in it derived from the spleen, lymphatic glands, thymus, and other tissues rich in leucocytes. To these substances Buchner gave the name of *alexines*. These substances are somewhat unstable compounds, and are destroyed by the action of light, and also by a temperature of 60° C. They can be precipitated by alcohol and by ammonium sulphate, and correspond in their general behaviour with enzymes or unorganised ferments. Regarding the existence in the serum of bactericidal substances which are very easily destroyed by heat there can be no doubt, but their properties can only be studied outside the body, and it must not be assumed that the serum in such conditions has always the same property as in the living body. In some cases, for example, the bactericidal power of the serum *in vitro* has been found to be greater than in a living animal. The bactericidal action, moreover, is manifested towards some organisms and not towards others, and this variation does correspond with the immunity of the animal against these organisms.

At present, therefore, the facts of natural immunity cannot be fully explained. In some cases the insusceptibility to toxic substances may explain the degrees of immunity possessed by different animals, whilst in others immunity may be due to special bactericidal powers possessed by them. What these bactericidal powers really are cannot be explained on any single theory. A vital activity of the tissues and fluids is, no doubt, brought about by the presence of the bacteria, and this cannot be fully imitated in experiments outside the body. The facts given above with regard to the action of antimicrobic serum, show how complicated a matter the bactericidal process may be. Further, in natural immunity a direct killing of the organisms by the fluids of the serum is not necessary. It may be sufficient that their growth is prevented, so that they ultimately die out or are taken up by the phagocytes.

APPENDIX A.

SMALLPOX AND VACCINATION.

SMALLPOX is a disease to which much study has been devoted, owing, on the one hand, to the havoc which it formerly wrought among the nations of Europe—a havoc which at the present day it is difficult to realise,—and on the other hand, to the controversies which have arisen in connection with the active immunisation against it introduced by Jenner. Though there is little doubt that a *contagium vivum* is concerned in its occurrence, the etiological relationship of any particular organism to smallpox has still to be proved, and with regard to Jennerian vaccination, it is only the advance of bacteriological knowledge which is now enabling us to understand the principles which underlie the treatment, and which is furnishing methods whereby, in the near future, the vexed questions concerned will probably be satisfactorily settled. We cannot here do more than touch on some of the results of investigation with regard to the disease.

Jennerian Vaccination.—Up to Jenner's time the only means adopted to mitigate the disease had been by inoculation (by scarification) of virus taken from a smallpox pustule, especially from a mild case. By this means it was shown that in the great majority of cases a mild form of the disease was originated. It had previously been known that one attack of the disease protected against future infection, and that the mild attack produced by inoculation

also had this effect. This inoculation method had long been practised in various parts of the world, and had considerable popularity all over Europe during the eighteenth century. Its disadvantage was that the resulting disease, though mild, was still infectious, and thus might be the starting-point of a virulent form among unprotected persons. Jenner's discovery was published when inoculation was still considerably practised. It was founded on the popular belief that those who had contracted cowpox from an affected animal were insusceptible to subsequent infection from smallpox. In the horse, there occurs a disease known as horsepox, or grease, especially tending to occur in wet cold springs, which consists in an inflammatory condition about the hocks, giving rise to ulceration. Jenner believed that the matter from these ulcers, when transferred by the hands of men who dressed the sores to the teats of cows subsequently milked by them, gave rise to cowpox in the latter. This disease was thus in reality identical with horsepox, in epidemics of which it had its origin. In the cow, it manifests itself as a papular eruption on the teats. The papules become pustules; their contents dry up to form scabs, or more or less deep ulcers are formed at their sites. From such a lesion the hands of the milkers may become affected through abrasions, and a similar local eruption occurs, with general symptoms in the form of slight fever, malaise, and loss of appetite. It is this illness which, according to Jenner, gives rise to immunity from smallpox infection. He showed experimentally that persons who had suffered from such attacks did not react to inoculation with smallpox, and further, that persons to whom he communicated cowpox artificially, were similarly immune. The results of Jenner's observations and experiments were published in 1798 under the title *An Inquiry into the Causes and Effects of the Variola Vaccinæ*. Though from the first Jennerian vaccination had many opponents, it gradually gained the confidence of the unprejudiced, and became extensively practised all over the world, as it is at the present day.

The evidence in favour of vaccination is very strong.

There is no doubt that inoculation with lymph properly taken from a case of cowpox, can be maintained with very little variation in strength for a long time by passage from calf to calf, and such calves are now the favourite source of the lymph used for human vaccination. When lymph derived from them is used for the latter purpose, immunity against smallpox is conferred on the vaccinated individual. It has been objected that some of the lymph which has been used has been derived from calves inoculated, not with cowpox, but with human smallpox. It is possible that this may have occurred in some of the strains of lymph in use shortly after the publication of Jenner's discovery, but there is no doubt that most of the strains at present in use have been derived originally from cowpox. The most striking evidence in favour of vaccination is derived from its effects among the staffs of smallpox hospitals, for here, in numerous instances, it is only the unvaccinated individuals who have contracted the disease. While vaccination is undoubtedly efficacious in protecting against smallpox, Jenner was wrong in supposing that a vaccination in infancy afforded protection for more than a certain number of years thereafter. It has been noted in smallpox epidemics which have occurred since the introduction of vaccination, that whereas young unprotected subjects readily contract the disease, those vaccinated as infants escape more or less till after the 13th to the 15th years. It has become, therefore, more and more evident that revaccination is necessary if immunity is to continue, and where this is done in any population, smallpox becomes a rare disease, as has happened in the German army, where the mortality is practically nil. The whole question of the efficacy of vaccination has recently been investigated in this country by a Royal Commission, whose general conclusions are as follows. Vaccination diminishes the liability to attack by smallpox, and when the latter does occur, the disease is milder and less fatal. Protection against attack is greatest during nine or ten years after vaccination. It is still efficacious for a further period of

five years, and possibly never wholly ceases. The power of vaccination to modify attack outlasts its power wholly to ward it off. Revaccination restores protection, but this operation must be from time to time repeated. Vaccination is beneficial according to the thoroughness with which it is performed.

The Relationship of Smallpox (Variola) to Cowpox (Vaccinia).—This is the question regarding which, since the introduction of vaccination, the greatest controversy has taken place; a subsidiary point has been the interrelationships within the group of animal diseases which includes cowpox, horsepox, sheep-pox, and cattle plague. With reference to smallpox and cowpox the problem has been, Are they identical or not? There is no doubt that cowpox can be communicated to man, in whom it produces the eruption limited to the point of inoculation, and the slight general symptoms which vaccination with calf lymph has made familiar. Apparently against the view that cowpox is a modified smallpox are the facts that it never reproduces in man a general eruption, and that the local eruption is only infectious when matter from it is introduced into an abrasion. The loss of infectiveness by transmission through the body of a relatively insusceptible animal is a condition of which we have already seen many instances in other diseases, and the uniformity of the type of the affection resulting from vaccination with calf lymph finds a parallel in such a disease as hydrophobia, where, after passage through a series of monkeys, a virus of attenuated but constant virulence can be obtained. We have seen that there are good grounds for believing that the virus of calf lymph confers immunity against human smallpox. In considering the relationships of cowpox and smallpox, this is an important though subsidiary point; for at present it is questionable whether there are any well-authenticated instances of one disease having the capacity of conferring immunity against another. The most difficult question in this connection is what happens when inoculations of smallpox matter are made on cattle. Chauveau denies that in such

circumstances cowpox is obtained. He, however, only experimented on adult cows. The transformation has been accomplished by many observers, including, in this country, Simpson, Klein, Hime, and Copeman. The general result of these experiments has been that if a series of calves is inoculated with variolous matter, in the first there may not be much local reaction, though redness and swelling appear at the point of inoculation, and some general symptoms manifest themselves. On squeezing some of the lymph from such reaction as occurs, and using it to continue the passages through other calves, after a very few transfers a local reaction indistinguishable from that caused by cowpox lymph generally takes place, and the animals are now found to be immune against the latter. Not only so, but on using for human vaccination the lymph from such variolated calves, results indistinguishable from those produced by vaccine lymph are obtained, and the transitory illness which follows, unlike that produced in man by inoculation with smallpox lymph, is no longer infectious. In fact many of the strains of lymph in use in Germany at present have been derived thus from the variolation of calves. The criticism of these experiments which has been offered, namely, that since many of them were performed in vaccine establishments, the calves were probably at the same time infected with vaccinia, is not of great weight, as in all the recent cases at least, very elaborate precautions have been adopted against such a contingency. And at any rate it would be rather extraordinary that this accident should happen to occur in every case. We can, therefore, say that at present there is the very strongest ground for holding not only that vaccinia confers immunity against variola, but that variola confers immunity against vaccinia. The *experimentum crucis* for establishing the identity of the two diseases would of course be the isolation of the same micro-organism from both, and the obtaining of all the results just detailed by means of pure cultures or the products of such. In the absence of this evidence we are at present justified in considering that there is strong reason

for believing that vaccinia and variola are the same disease, and that the differences between them result from the relative susceptibilities of the two species of animals in which they naturally occur.

With regard to the relation of cowpox to horsepox, it is extremely probable that they are the same disease. Some epidemics of the former have originated from the horse, but in other cases such a source has not been traced. Cattle plague from the clinical standpoint, and also from that of pathological anatomy, resembles very closely human smallpox. Though each of the two diseases is extremely infectious to its appropriate animal, there is no record of cattle plague giving rise to smallpox in man or *vice versâ*. When matter from a cattle plague pustule is inoculated in man, a pustule resembling a vaccine pustule occurs, and further, the individual is asserted to be now immune to vaccination; but vaccination of cattle with cowpox lymph offers no protection against cattle plague, though some have looked on the latter as merely a malignant cowpox. Sheep-pox also has many clinical and pathological analogies with human smallpox, and facts as to its relation to cowpox vaccination similar to those observed in cattle plague, have been reported. Smallpox, cowpox, cattle plague, horsepox, and sheep-pox, in short, constitute an interesting group of analogous diseases of the true relationships of which to one another we are, however, still ignorant.

Micro-organisms associated with Smallpox.—Burdon Sanderson was among the first to show that in vaccine lymph there were certain bodies which he recognised as bacteria. Since then numerous observations have been made as to the occurrence of such in matter derived from variolous and vaccine pustules. In especially the later stages of the latter, many of the pyogenic organisms are always present, *e.g.*, *staphylococcus aureus* and *staphylococcus cereus flavus*, and many of the ordinary skin saprophytes also are often present, but no organism has ever been isolated which on transference to animals has been shown to have any specific relationship to the disease. A bacillus, however,

discovered independently by Klein and Copeman, and at present *sub judice*, may afford better results. Klein observed this organism in lymph taken from a vaccine pustule in a calf on the fifth and sixth days, in human vaccine lymph on the eighth day, and in lymph from a smallpox pustule on the fourth day. To demonstrate the bacilli, cover-glass films are dried and placed for five minutes in acetic acid (1 in 2), washed in distilled water, dried, and placed in alcoholic gentian-violet for from twenty-four to forty-eight hours, after which they are washed in water and mounted. Copeman and Kent also found the bacilli in sections of vaccine pustules stained by Löffler's methylene-blue, or by Gram's method. The organisms are .4 to .8 μ in length, and one-third to a half of this in thickness. They are generally thinner and stain better at the ends than at the middle. They occur in groups of from three to ten in both the lymph and the tissues. In the centre of the protoplasm there is often a clear globule, which is looked on as a spore. They have hitherto resisted attempts at cultivation, a fact which is rather in favour of their non-saprophytic nature, but recently (April 1897) Copeman has announced that he has succeeded in growing them on artificial media. The facts that this bacillus is one hitherto not recognised microscopically, that it exists in the pustules, the contents of which are probably the means by which the disease naturally spreads, that it resists artificial cultivation, that the possession by it of spores explains some of the characteristics of vaccine lymph (resistance to drying, etc.), make its further investigation a matter of considerable interest.

Various observers have described appearances in the epithelial cells in the neighbourhood of the smallpox or vaccine pustules, which they have interpreted as being protozoa. Thus Ruffer and Plimmer describe as occurring in clear vacuoles in the cells of the rete Malpighii at the edge of the pustule, in paraffin sections of vaccine and smallpox pustules carefully hardened in alcohol, and stained by the Ehrlich-Biondi mixture, small round bodies about four times the size of a staphylococcus

pyogenes, coloured red by the acid fuchsin, sometimes with a central part stained by the methyl-green. These appear to multiply by simple division, and in the living condition exhibit amœboid movement. Similar bodies have been described in so many conditions that as yet it is impossible to assign any specific significance to them.

The Nature of Vaccination.—As we are ignorant of the cause of smallpox, we can only conjecture what the nature of vaccination is. From what we know of other like processes, however, we have some ground for believing that it consists in an active immunisation by means of an attenuated form of the causal organism. As to how immunity is maintained after vaccination, we do not know much. Some, including Béclère, Chambon, and Ménard (who jointly investigated the subject), maintain that in the blood of vaccinated animals substances exist which, when transferred to other animals, can confer a certain degree of passive immunity against vaccination, and which have also a degree of curative action in animals already vaccinated. Beumer and Peiper, on the other hand, could not find evidence of the existence of such bodies. If they do exist, we cannot as yet say whether they are antitoxic or antimicrobic.

APPENDIX B.

HYDROPHOBIA.

SYNONYMS.—RABIES: FRENCH, LA RAGE: GERMAN, LYSSA, DIE HUNDSWUTH.

Introductory.—Hydrophobia is an infectious disease which in nature occurs epidemically chiefly among the carnivora, especially in the dog and the wolf. Infection is carried by the bite of a rabid animal or by a wound or abrasion being licked by such. The disease can be transferred to other species, and when once started can be spread from individual to individual by the same paths of infection. Thus it occurs epidemically from time to time in cattle, sheep, horses, and deer, and can be communicated to man; but in modern times at least, infection practically never takes place from man to man, though such an occurrence is quite possible.

In Western Europe the disease is most frequently observed in the dog; but in Eastern Europe, especially in Russia, epidemics among wolves constitute a serious danger both to other animals and to man. All the manifestations of the disease point to a serious affection of the nervous system; but inasmuch as symptoms of excitement or of depression may predominate, it is customary to describe clinically two varieties of rabies, (1) rabies proper, or furious rabies (*la rage vraie, la rage furieuse: die rasende Wuth*); and (2) dumb madness or paralytic rabies

(*la rage mue: die stille Wuth*). The disease, however, is essentially the same in both cases. In the dog the furious form is the more common. After a period of incubation of from three to six weeks, the first symptom noticed is a change in the animal's aspect; it becomes restless, and it tears up and swallows unwonted objects; it has a peculiar high-toned bark. Spasms of the throat muscles come on, especially in swallowing, and there is abundant secretion of saliva; its supposed fear of water is, however, a myth. Gradually convulsions, paralysis, and coma come on; and death supervenes. In the paralytic form, the early symptoms are the same, but paralysis appears sooner. The lower jaw of the animal drops, from implication of the elevator muscles, all the muscles of the body become more or less weakened, and death ensues without any very marked irritative symptoms.

In man the incubation period after infection varies from fifteen days to seven or eight months, or even longer, but is usually about forty days. When symptoms of rabies are about to appear, certain prodromata, such as pains along the nerves of the limb in which the wound has been received, may be observed. To this succeeds a stage of nervous irritability, during which all the reflexes are augmented—the victim starting at the slightest sound, for example. There are spasms especially of the muscles of deglutition and respiration, and cortical excitement evidenced by delirium may occur. On this follows a period in which all the reflexes are diminished, weakness and paralysis are observed, convulsions occur, and finally coma and death supervene. The duration of the acute illness is usually from four to eight days. The existence of paralytic rabies in man has been denied by some, but it undoubtedly occurs. This is usually manifested by paralysis of the limb in which the infection has been received, and of the neighbouring parts; but while in such cases this is often the first symptom observed, during the whole of the illness the occurrence of widespread paralysis is the outstanding feature. When once symptoms of hydro-

phobia, of whichever kind, arise, a fatal issue is absolutely certain.

While a source of infection undoubtedly occurs in all cases of hydrophobia, and can usually be traced, the results of all attempts to determine the morbific cause have been unsatisfactory. Various bacteria have, on insufficient evidence, been described as associated with the disease. Recently, however (1896), Bruschettini, by using media containing lecithin and matters extracted from the brain, claims to have isolated a bacillus which reproduces rabies in animals. The disease presents so many analogies with other conditions arising from bacteria or other micro-organisms, that for this reason alone it requires our attention, and besides, the principles which underly the great work of Pasteur on this subject are essentially those which, applied to diseases undoubtedly bacterial in origin, have been prolific in results similar to his.

The Pathology of Hydrophobia.—In hydrophobia as in tetanus, to which it bears more than a superficial resemblance, the appearances presented in the nervous system, to which all the symptoms are naturally referred, are comparatively unimportant. On naked-eye examination, congestions, and, it may be, minute hæmorrhages in the central nervous system, are the only features noticeable. Microscopically, there have been described in the cells of the anterior cornua of the grey matter in the spinal cord, and also in the nuclei of the cranial nerves, various degenerations. These include pigmentation, atrophy, and vacuolation of the protoplasm, and the occurrence of a deposit of granules in the nucleus. In the white matter, especially in the posterior columns, swelling of the axis cylinders and breaking up of the myeline sheaths have been noted, and similar changes occur also in the spinal nerves, especially of the part of the body through which infection has come. In the nervous system also some have seen minute bodies which they have considered to be cocci, but that they are really such there is no evidence. The changes in the other parts of the body are unimportant.

Thus, both from the clinical and histological standpoints, the nervous system is the centre of the disease. Experimental pathology confirms this view by finding in the nervous system a special concentration of what, from want of a more exact term, we must call the hydrophobic virus. Earlier inoculation experiments with material from various parts of animals dead of rabies, had not given uniform results, as whatever was the source of the material, the disease was not invariably produced. Such experiments had been made by subcutaneous injection. Pasteur's first contribution to the subject was to show that the most certain method of infection was by inserting the infective matter beneath the dura mater. Not only was the disease invariably produced where materials from certain sources were thus used, but the natural period of incubation was shortened. It was then found that in the case of any animal or man dead of the disease, injection by the above method, of emulsions of any part of the central nervous system, of the cerebro-spinal fluid, or of the saliva, gave rise to rabies; and, further, the identity of the furious and paralytic forms was proved, as sometimes the one, sometimes the other, was produced, whatever form had been present in the original case. Infection with the blood of rabic animals does not reproduce the disease. There is evidence, however, that the poison also exists in such glands as the pancreas and mamma. Subcutaneous infection with part of the nervous system of an animal dead of rabies usually gives rise to the disease.

In consequence of the introduction of this more reliable inoculation method, further information has been acquired regarding the spread and distribution of the virus in the body. Gaining entrance by the infected wound, it early manifests its affinity for the nervous tissues. It reaches the central nervous system by spreading up the peripheral nerves. This can be shown by inoculating an animal subcutaneously in one of its limbs, with virulent material. If now the animal be killed before symptoms have manifested themselves, rabies can be produced by subdural inoculation

from the nerves of the limb which was infected. Further, rabies can often be produced from such a case by subdural infection with the part of the spinal cord into which these nerves pass, while the other parts of the animal's nervous system do not give rise to the disease. This explains how the initial symptoms of the disease (pains along nerves, paralyses, etc.) so often appear in the infected part of the body, and it probably also explains the fact that bites in such richly nervous parts as the face and head are much more likely to be followed by hydrophobia than bites in other parts of the body. Again, injection into a peripheral nerve, such as the sciatic, is almost as certain a method of infection as injection into the subdural space, and gives rise to the same type of symptoms as injection into the corresponding limb. Intravenous injection of the virus, on the other hand, differs from the other modes of infection in that it more frequently gives rise to paralytic rabies. This fact Pasteur explained by supposing that the whole of the nervous system in such a case becomes simultaneously affected. The virus seems to have an elective affinity for the salivary glands, as well as for the nervous system. Roux and Nocard found that the saliva of the dog became virulent three days before the first appearance of symptoms of the disease.

As we have said, of the *causa causans* in hydrophobia we are ignorant. There is no evidence that the granules observed in the nervous system of animals dead of this disease are bacteria, and no organisms which certainly reproduce rabies have been cultivated from any part of the body of such animals. We are likewise ignorant of the nature of the hydrophobic virus. Whether it is a ferment, as the occurrence of such a marked period of incubation might indicate, we do not know. It must be of a fairly stable nature, as the nervous system containing it is virulent till destroyed by putrefaction. Further, Jobert kept a rabbit's nervous system for a year at $-10°$ to $-20°$ C., and found that its virulence remained unimpaired. Whatever its nature may be, the potency of the virus seems to vary. Such

variation may occur in nature. Thus, while the death rate among persons bitten by mad dogs is about 16 per cent, the corresponding death rate after the bites of wolves is 80 per cent. Here, however, it must be kept in view that, as the wolf is naturally the more savage animal, the number and extent of the bites, *i.e.*, the number of channels of entrance of the virus into the body, and the total dose, are greater than in the case of persons bitten by dogs. As we shall see, alterations in the potency of the virus can certainly be effected by artificial means.

The Prophylactic Treatment of Hydrophobia. — Until the publication of Pasteur's researches in 1885, the only means adopted to prevent the development of hydrophobia in a person bitten by a rabid animal, had consisted in the cauterisation of the wound. Such a procedure was undoubtedly not without effect. It has been shown that cauterisation within five minutes of the infliction of a rabic wound prevents the disease from developing, and that if done within half an hour, it saves a proportion of the cases. After this time, cauterisation only lengthens the period of incubation; but, as we shall see presently, this is an extremely important effect, and undoubtedly in every case of a suspected bite, cauterisation ought to be practised.

The work of Pasteur has, however, revolutionised the whole treatment of wounds inflicted by hydrophobic animals. Pasteur started with the idea that, since the period of incubation in the case of animals infected subdurally from the nervous systems of mad dogs, is constant in the dog, the virus has been from time immemorial of constant strength. Such a virus, of what might be called natural strength, is usually referred to in his works as the virus of *la rage des rues*, in the writings of German authors as the virus of *die Strasswuth*. Pasteur found on inoculating a monkey subdurally with such a virus, and then inoculating a second monkey from the first, and so on with a series of monkeys, that it gradually lost its virulence, as evidenced by lengthened periods of incubation on subdural inoculation of dogs, until it wholly lost the power of producing rabies in dogs, when intro-

duced subcutaneously. When this point had been attained, its virulence was not diminished by further passage through the monkey. On the other hand, if the virus of *la rage des rues* were similarly passed through a series of rabbits or guinea-pigs, its virulence was increased till a constant strength (the *virus fixé*) was attained. Pasteur had thus at command three varieties of virus—that of natural strength, that which had been attenuated, and that which had been exalted. He further found that, commencing with the subcutaneous injection of a weak virus and following this up with the injection of the stronger varieties, he could ultimately, in a very short time, immunise dogs against subdural infection with a virus which, under ordinary conditions, would certainly have caused a fatal result. He also elucidated the fact that the exalted virus contained in the spinal cords of rabbits such as those referred to, could be attenuated so as no longer to produce rabies in dogs by subcutaneous injection. This was done by drying the cords in air over caustic potash (to absorb the moisture), the diminution of virulence being proportional to the length of time during which the cords were kept. Accordingly, by taking a series of such spinal cords kept for various periods of time, he was supplied with a series of vaccines of different strengths. Pasteur at once applied himself to find whether the comparatively long period of incubation in man could not be taken advantage of to "vaccinate" him against the disease before its gravest manifestation took place. The following is the record of the first case thus treated. The technique was to rub up in a little sterile bouillon a small piece of the cord used, and inject it hypodermically by means of a Pravaz's syringe. The first injection was made with a very attenuated virus, *i.e.*, a cord fourteen days old. In subsequent injections the strength of the virus was gradually increased, as shown in the table :—

July	7,	1885,	9 A.M.,	cord of	June	23,	*i.e.*	14	days old.
,,	7	,,	6 P.M.	,,		25	,,	12	,,
,,	8	,,	9 A.M.	,,		27	,,	11	,,
,,	8	,,	6 P.M.	,,		29	,,	9	,,

July	9,	1885,	11 A.M.,	cord of	July	1	*i.e.*	8 days old.
,,	10	,,	,,	,,		3	,,	7 ,,
,,	11	,,	,,	,,		5	,,	6 ,,
,,	12	,,	,,	,,		7	,,	5 ,,
,,	13	,,	,,	,,		9	,,	4 ,,
,,	14	,,	,,	,,		11	,,	3 ,,
,,	15	,,	,,	,,		13	,,	2 ,,
,,	16	,,	,,	,,		15	,,	1 day old.

The patient never manifested the slightest symptom of hydrophobia. Other similarly favourable results followed; and this prophylactic treatment of the disease quickly gained the confidence of the scientific world, which it still maintains. (The principle is, of course, the same as in artificially developing a high degree of active immunity against a bacterial infection.) The only modification which the method has undergone, has been in the treatment of serious cases, such as multiple bites from wolves, extensive bites about the head, especially in children, cases which come under treatment at a late period of the incubation stage, and cases where the wounds have not cicatrised. In such cases the stages of the treatment are condensed. Thus on the first day, say at 11 A.M. and 4 P.M. and 9 P.M., cords of 12, 10, and 8 days respectively are used; on the second day, cords of 6, 4, and 2 days; on the third day, a cord of 1 day; on the fourth day, cords of 8, 6, and 4 days; on the fifth, cords of 3 and 2 days; on the sixth, cords of 1 day; and so on for 10 days. The success of the treatment has been very marked. The statistics of the cases treated in Paris are published quarterly in the *Annales de l'Institut Pasteur*, and general summaries of the results of each year are also prepared. As we have said, the ordinary mortality formerly was 16 per cent of all persons bitten. During the ten years 1886-95, 17,337 cases were treated, with a mortality of .48 per cent. It has been alleged that many people are treated who have been bitten by dogs that were not mad. This, however, is not more true of the cases treated by Pasteur's method than it was of those on which the ordinary mortality of 16 per cent was based, and care is taken in making up the statistics to distinguish the cases

into three classes. Class A includes only persons bitten by dogs proved to have had rabies, by inoculation in healthy animals of parts of their central nervous system. Class B includes those bitten by dogs that a competent veterinary surgeon has pronounced to be mad. Class C includes all other cases. During 1895, 122 cases belonging to Class A were treated, with no deaths; 949 belonging to Class B, with two deaths; and 449 belonging to Class C, with no deaths. Besides the Institute in Paris, similar institutions exist in other parts of France, in Italy, and especially in Russia, as well as in other parts of the world; and in these similar success has been experienced. It may be now taken as established, that a very grave responsibility rests on those concerned, if a person bitten by a mad animal is not subjected to the Pasteur treatment. Two practical points in dealing with such a case are to be noted: (1) the wounds ought to be cauterised with the actual cautery as soon as possible; and (2) if the person is sent to a Pasteur institute, the head of the animal which inflicted the bite ought also to be sent packed in ice, in order that by inoculation its madness may be definitely ascertained.

Antirabic Serum.—In the early part of the present century an Italian physician, Valli, showed that immunity against rabies could be conferred by administering through the stomach progressively increasing doses of hydrophobic virus. Following up this observation, Tizzoni and Centanni have attenuated rabic virus by submitting it to peptic digestion, and have immunised animals by injecting gradually increasing strengths of such virus. This method is usually referred to as the Italian method of immunisation. The latter workers showed from this that the serum of animals thus immunised could give rise to passive immunity in other animals; and further, that if injected into animals from 7 to 14 days after infection with the virus, it prevented the latter from producing its fatal effects, even when symptoms had begun to manifest themselves. They further succeeded in producing in the sheep and the dog an immunity equal to from 1-25,000 to 1-50,000 (*vide*

p. 439), and they recommended the use, in severe cases, of the serum of such animals in addition to the treatment of the patient by the Pasteur method. The serum seems to contain antitoxic bodies similar to those produced under similar circumstances in other diseases, and these act as direct stimulants of the nervous system.

APPENDIX C.

MALARIAL FEVER.

THE organism which is now almost universally believed to be the causal agent in malarial fever was discovered by Laveran in 1880. This organism does not belong to the vegetable but to the animal kingdom; it is not a bacterium but a protozoon. It is usually known as the plasmodium or hæmatozoon, malariæ. Laveran's discovery received confirmation from the independent researches of Marchiafava and Celli, and later from the researches of many others in various parts of the world. Valuable additional information on the subject was supplied by the work of Golgi, who specially has the credit of first distinguishing certain varieties of the organism in the different types of malarial fever. In this country valuable work on the subject has been done by Manson. Regarding the invariable presence of this organism in the blood, and the cycle of changes which it undergoes in relation to the paroxysms of fever, practically all are agreed. On the other hand, some doubt still prevails regarding certain stages in its development, and especially regarding the number of varieties of the organism and their relations to one another. We shall first give an account of the different forms in which the organisms are met with, and afterwards state some facts with regard to the varieties which have been described. The description will be simplified by stating that the parasites in all the types of malarial fever pass through a definite cycle of

development, which is completed in a period of time corresponding to the type of the fever; that is, in the quotidian[1] in twenty-four hours, in the tertian in forty-eight hours, in the quartan in seventy-two hours. In this cycle the youngest forms of the parasite appear as minute rounded protoplasmic bodies, which are at first free in the blood plasma but afterwards become attached to and invade the red corpuscles. Within the latter they gradually increase in size, till at a certain period multiplication by division or sporulation takes place, which results in the setting free of a number of young forms; thus the cycle is completed. We may state then that there is a stage of gradual growth of the parasite, which is followed by a stage of sporulation or the formation of a new generation of young forms. The latter stage corresponds more or less closely with the rigor at the onset of the attack of fever. The parasites are always most abundant in the blood during the attack of fever, and in the intervals become greatly diminished in number or may practically disappear. They are also as a rule more abundant in internal organs than in the peripheral blood, and in some types of fever the process of sporulation is practically confined to the former.

In addition to the forms which appear to constitute stages in this regular process of development there are two others, namely, the *crescentic bodies* and the *flagellated organisms*.

These different forms may now be described in more detail.

1. The *spores* are the youngest and smallest forms, which result from the segmentation of the adult parasite. They are rounded or oval protoplasmic bodies of minute size, usually not measuring much more than 1 μ in diameter, their exact size, however, varying in the different types of fever. They possess little or no amœboid movement. They remain free in the serum for a short time, but soon attack the red corpuscles, when they become the intracorpuscular amœboid bodies.

[1] A quotidian type may, however, be produced by two generations of tertian parasites with a twenty-four hours' interval, etc.

2. *Epi-* or *Intra-corpuscular Bodies.*—These include the parasites which have attacked the red corpuscles; they are at first situated on the surface of the latter but afterwards penetrate their substance. They usually occur singly in the red corpuscles, but sometimes two or more may be present together. The youngest or smallest forms appear as minute colourless specks, scarcely exceeding 1 μ in diameter. As seen in the fresh blood, they exhibit more or less active amœboid movement, showing marked variations in shape. The amount and character of the amœboid movement varies somewhat in different types of fever. As they increase in size, pigment appears in their interior as minute brownish specks, and gradually becomes more abundant (Figs. 102, 103). The pigment may be scattered through their substance, or concentrated at one or more points, and often shows vibratory or oscillating movements. This pigment is no doubt derived from the hæmoglobin of the red corpuscles, the parasites growing at the expense of the latter. The red corpuscles thus invaded may remain unaltered in appearance, may become swollen and pale, or somewhat shrivelled and of darker tint. In stained specimens a nucleus may be seen as a pale spot containing a minute and deeply-stained nucleolus, the nucleus being more distinct at some stages than at others. Sometimes, namely in the quotidian and malignant fevers, the parasite passes into a quiescent "ring form." The organisms in this condition show a well-defined outer circular margin and a central spot which is less sharply marked off, the pigment being usually collected in a small clump at one side (Fig. 105). These ring forms may again assume amœboid movement.

Within the red corpuscles the parasites gradually increase in size till the full adult form is reached (Fig. 103). In the latter stage the parasite loses its amœboid movement more or less completely, has a somewhat rounded form, and contains a considerable amount of pigment. Sometimes, for example in the quotidian form, it only occupies a fraction of the red corpuscle. The adult parasites may

FIG. 102.

FIG. 103.

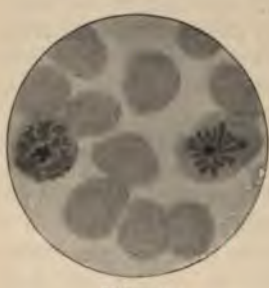

FIG. 104.

FIG. 105.

FIG. 106.

FIG. 107.

FIGS. 102-107.—From dried blood-films showing parasites of malarial fever. Magnified about 1000 diameters.

Fig. 102. Early intracorpuscular form of the "mild tertian" parasite. Fig. 103. Large intracorpuscular form of the same parasite, showing scattered pigment granules; the invaded red corpuscle is much enlarged. Fig. 104. Two members of the "rosette" series of the same parasite; that to the right shows the radiate segmentation, that to the left is an earlier stage. In both the pigment is collected in the centre. Fig. 105. Two "ring-forms" of the quotidian parasite, within red corpuscles. Fig. 106 shows a "crescentic body"; from a case of malignant tertian fever. Fig. 107. A flagellated organism, derived outside the body from a crescentic form. (All these figures are from negatives or preparations, kindly lent by Dr. Patrick Manson.)

then undergo segmentation, *i.e.*, sporulation, but not all of them do so; many become degenerated and ultimately break down.

3. *Segmentation or Sporulation Forms.*—In the process of segmentation or sporulation, the pigment becomes collected into a small central mass, and from it as a centre, lines radiate outwards and divide the protoplasm into regular segments (Fig. 104). In this way a characteristic appearance is produced which has given the name of "rosette form" to this stage. The segments or spores thus formed vary in number and also in size, in different types of fever. They become more or less rounded in shape and are set free in the blood plasma. The pigment granules remain apart from the spores, sometimes surrounded by a portion of the substance of the parasite, and are chiefly taken up by leucocytes. The process of segmentation, however, does not occur in all forms of malarial fever in this radiate fashion, but in some takes place more or less irregularly.

4. Peculiar forms are those known as *crescents* or *crescentic bodies*. These are non-amœboid, and of crescentic or sausage shape, usually measuring 8 to 9 μ in length. Occasionally a fine curved line is seen joining the extremities on their concave aspect, which probably represents the remains of the envelope of a red corpuscle (Fig. 106). They are colourless and transparent, have a distinct enclosing membrane, and usually show a small collection of granular pigment about their middle. Mannaberg's view regarding the origin of the crescentic bodies is that they are conjugation-forms, resulting from the fusion of two intracorpuscular bodies. He gives to them the name of "syzygies." They are not found in all the types of malarial fever, but especially in the quotidian and malignant types, and possibly do not represent a stage in the ordinary cycle of development. They appear in the blood after the fever has lasted for some time, apparently remain unchanged through the attacks of pyrexia, and may persist for a considerable period after the fever has gone, being often present in the cachexia or anæmia following these fevers.

5. *Flagellated Organisms.*—If a drop of blood be examined under the microscope for some time, flagellated organisms may be found. So far as is known, they do not occur as such in the circulating blood, but only appear in the blood outside the body. They are derived from the crescents or from the larger pigmented intracorpuscular bodies. In the former case, when watched under the microscope the crescents alter their shape, becoming straight, then oval, and ultimately spherical. The pigment granules first become arranged as a ring, and afterwards show a peculiar vibratory movement, which is apparently produced by flagella which have formed within the sphere. When this stage is reached, the flagella, usually three or four, though sometimes more, are shot through the envelope, sometimes simultaneously, sometimes one after the other, and present a very rapid lashing action. The flagella are very delicate filaments, with sometimes a slight bulbous swelling at their free extremity (Fig. 107). They may afterwards become detached, and move away with an active independent movement. In the case of their development from the large intracorpuscular bodies, the pigment shows an agitated movement in the same way, and ultimately the flagella are suddenly shot out.

There has been, and still is, great diversity of opinion concerning the nature of the crescentic and the flagellated bodies. The view which appears to be best supported is, that the former represent a sort of resting form for the life of the organisms outside the body, the first stage of which is the flagellated condition. This view has been advanced notably by Manson, who considers that the flagella are really flagellated spores which undergo further change, and that this probably occurs in the body of mosquitoes which have taken up blood containing the parasite. Ross supports this view, and has found that in the body of the mosquito many of the crescents become spherical, and develop into the flagellated forms. Hitherto it has not been found possible to infect healthy individuals by allowing them to be bitten by mosquitoes containing the parasites. Possibly, as Manson suggests, the latter undergo further change, and are

set free on the death of the insect, thus gaining access to water. But regarding this, definite evidence is still required.

Varieties of the Malarial Parasite.—The view propounded by Laveran is that there is only one species of malarial parasite, which is polymorphous, and presents slight differences in structural character in the different types of fever. This view is now held by only a small minority of authorities, and it is generally believed that there are several distinct varieties, though there is still diversity of opinion as to their exact number. There is, however, a fairly general agreement as to the division of the varieties of malarial fever, according to the characters of the parasite, into two main classes; the first including the milder forms, tertian and quartan, and the second including the quotidian, malignant, and certain irregular forms. The following arrangement follows closely that of Marchiafava and Bignami, and of Mannaberg.

(*a*) *Milder forms, in which crescentic bodies do not occur.*—The parasites of the quartan and tertian fevers ("winter-spring" fevers of Italian writers) were first distinguished by Golgi. Their characters are the following:—

1. *Quartan.*—The parasite passes through its cycle of development in twelve hours, and all the various stages are found in the blood. Only the smaller forms within the red corpuscles show amœboid movements, and these are not of very active character. The red corpuscles invaded by the parasite do not become decolorised or altered in size; the pigment granules are somewhat coarse. Typical rosette-forms are seen in the process of sporulation, which results in the formation of six to twelve segments or spores. The spores in the fresh blood show a central clear spot which is not seen in the spores of the tertian parasite.

2. *Tertian.*—The cycle of development of the parasite is completed in forty-eight hours. The young forms within the red corpuscles show much more active movement than in the quartan type, and give off longer and more slender processes, whilst the pigment granules are finer. The infected corpuscles become swollen and pale. Sporulation,

1. *Quotidian.*—This is th
assumed by malarial fever in ti
passes through its cycle of de
hours. Within the red corpuscle
size, and even in its adult conc
sporulation, does not usually occ
the corpuscle. The amœboid fc
"ring-form" described above. Ir
ment they acquire very fine dust-
adult quiescent form the pigment
small dark body. The spores (u
formed by irregular segmentation,
process takes place almost exclusi
spleen, etc., so that as a rule no sp
found in the blood taken in the usu

A non-pigmented quotidian p
entiated and described by Marchi
the previous only in the absence of

2. *Malignant Tertian or Summ*
chiafava and Bignami).—The pa
that of the quotidian. Its cycle of
occupies forty-eight hours, and the
without pigment for twenty-four
activity is maintained even in the
There are also some minor points

may be found in the brain and internal organs. In some fatal cases with coma, the cerebral capillaries may appear to be almost filled with them.

Irregular types of fever, sometimes of a continued character, may be produced by infection with different generations of the same variety of parasite, or by different varieties (mixed infections). In the various tropical malarial fevers it is quite possible that there are still other varieties of parasites whose characters have not yet been worked out.

Relations to the Disease.—Though the malarial parasites have in no form been cultivated outside the body, the evidence that they are the cause of the disease amounts to a practical certainty. They are always present in the disease, and have been found in no condition apart from malaria. Their cycle of development also corresponds in a remarkable manner with the course of the fever, each febrile attack being accompanied by the appearance of a new generation of parasites in the blood. In all probability the fever is produced by toxic bodies set free by the young parasites, but that cannot yet be directly proved. The presence of the parasites in the red corpuscles and the destruction of their substance which takes place, explain the occurrence of the anæmia which so often results, the subsequent distribution and storage of the altered hæmoglobin producing the pigmentary changes in the various organs.

The disease can also be communicated from one person to another by injecting the blood containing the parasites. Several experiments of this kind have been performed (usually about $\frac{1}{2}$ to 1 c.c. of blood has been used), and the result is more certain in intravenous than in subcutaneous injection. In such cases there is an incubation period, usually of seven to fourteen days, after which the fever occurs. The bulk of evidence goes to show that the same type of fever is reproduced as was present in the patient from whom the blood was taken.

It may also be mentioned that in certain affections of

birds and reptiles, parasites of somewhat similar character to those in malaria, though of distinct species, occur in the blood of these animals.

Methods of Examination.—The parasites may be studied by examining the blood in the fresh condition, or by permanent preparations. In the former case, a slide and cover-glass having been thoroughly cleaned, a small drop of blood from the finger or lobe of the ear is caught by the cover-glass, and allowed to spread out between it and the slide. It ought to be of such a size that only a thin layer is formed. A ring of vaseline is placed round the edge of the cover-glass to prevent evaporation. For satisfactory examination an immersion lens is to be preferred. The amœboid movements are visible at the ordinary room temperature, though they are more active on a warm stage. With an Abbé condenser a small aperture of the diaphragm should be used.

Permanent preparations are best made by means of dried films. A small drop of blood is allowed to spread itself out between two cover-glasses, which are separated by sliding the one on the other. The films are then allowed to dry. A very good method is that of Manson, who catches the drop of blood on a piece of gutta-percha tissue, and then makes a film on a clean slide by drawing the blood over the surface. The dried films are then fixed by heating for half an hour at 115° to 120° C., or by placing them in a mixture of equal parts of alcohol and ether for the same time, or by placing them in a saturated solution of corrosive sublimate for five minutes. In the last method they should be washed well in water before staining. They may be stained by a saturated watery solution of methylene-blue for five minutes, or by Ehrlich-Biondi fluid for half an hour. A double stain may be obtained by staining first with a 1 per cent watery solution of eosin for five minutes, then washing well in water, and thereafter staining for two to three minutes with a saturated watery solution of methylene-blue ; the red corpuscles are red, the parasites and nuclei of leucocytes are coloured

with the blue. After being stained the films are washed in water, dried, and mounted in balsam; those stained with Ehrlich-Biondi fluid are for some purposes best examined in the dry condition, the cover-glass being fixed at its margins to the slide by balsam, the film downwards, but not in contact with the slide.

APPENDIX D.

DYSENTERY.

Amongst the early researches on the relation of organisms to this disease probably the most important are those of Lösch, who noted the presence and described the characters of amœbæ in the stools of a patient suffering from dysentery, and considered that they were probably the causal agents. Further observations on a more extended scale were made by Kartulis with confirmatory results, this observer finding the same organisms also in liver abscesses associated with dysentery. The subject was, however, complicated by the fact that the same or closely similar organisms had been previously found in the intestine in normal conditions and in other diseases than dysentery (by Cunningham and Lewis and others), and additional research confirmed these results. Two questions thus arose. In the first place, Is there an amœba peculiar to dysentery (amœba dysenteriæ) and distinguishable from the amœbæ present in other conditions? In the second place, Is this organism the cause of the disease? Both of these questions may now be said to be practically answered in the affirmative. It has, moreover, been found that so far as etiology is concerned there are several forms of dysentery, and that it is the endemic dysentery of the tropics and of some sub-tropical countries which is produced by amœbæ. Hence this form is often now called *amœbic dysentery*, and Councilman and Lafleur, working in Baltimore, have found that it can be

distinguished from other forms not only by the presence of amœbæ but also by its pathological anatomy. The results of these observers have been confirmed by those obtained in Egypt by Kruse and Pasquale, who have also supplied important facts regarding the pathogenic effects of the amœbæ when inoculated into animals. The following description is chiefly taken from the monographs of the four writers last mentioned.

Amœbic Dysentery—Characters of the Amœba.—The amœbæ, as seen in the stools in a case of dysentery,

FIG. 108.—Amœbæ of dysentery.

a and *b*, amœbæ as seen in the fresh stools, showing blunt amœboid processes of ectoplasm. The endoplasm of *a* shows a nucleus, three red corpuscles and numerous vacuoles; that of *b*, numerous red corpuscles and a few vacuoles.

c, an amœba as seen in a fixed film preparation, showing a small rounded nucleus (Kruse and Pasquale). × 600.

are rounded or somewhat irregular protoplasmic masses, usually measuring about 25 to 35 μ in diameter, though both larger and smaller forms are met with.

When the parasite is at rest it has a more or less rounded shape; the protoplasm is finely granular and of refractile appearance, and is without differentiation into layers. The organism may show amœbic movements which are usually of a sluggish character, but are sometimes pretty rapid on a warm stage. When these occur, the amœba shows

differentiation into a central granular endoplasm and an outer hyaline layer or ectoplasm which is very thin and well marked off from the former. The blunt processes which are protruded in amœbic movement are composed of the ectoplasm (Fig. 108). By the amœbic movements slow locomotion may be produced. The amœbæ often show vacuoles in their substance, and may contain numerous red corpuscles (which appear to undergo digestive liquefaction), also bacteria, etc. There is a single nucleus which lies in the central part of the organism and usually measures about 6 to 8 μ in diameter. It is round or oval and contains a nucleolus. In the living condition the nucleus is invisible or is faintly seen, but becomes very evident on the addition of acetic acid, etc. The amœbæ break down pretty rapidly outside the body, and examination of the dysenteric stools twenty-four hours after being passed, usually fails to detect any of them. It is only on one or two rare occasions that the process of division of the amœbæ has been observed and described.

By some there have also been described encysted forms. These are of smaller size, about 10 to 15 μ, with a well-marked capsule, sometimes showing a double contour and a central protoplasm in which a nucleus may or may not be visible. It is still doubtful, however, whether these structures really constitute a stage in the development of the organism, as direct transformation from the one form into the other has not been observed.

Distribution of the Amœbæ.—As already stated, they are usually found in large numbers in the contents of the large intestine in tropical dysentery. They also, however, penetrate into the tissues, where they appear to exert a well-marked action. They are found in the mucous membrane when ulcers are being formed, but their most characteristic site is beyond the ulcerated area, where they may be seen penetrating deeply into the submucous, and even into the muscular coats. In these positions they may be unattended by any other organisms, and the tissues around them show more or less necrotic change without much accompanying

inflammatory reaction. In this way the ulcers are lined by sloughing tissue, and have often an undermined character. These lesions are considered by Councilman and Lafleur to be characteristic of amœbic dysentery. In the liver abscesses associated with dysentery the amœbæ are usually to be found, and not infrequently are the only organisms present. The action here on the tissues is of an analogous nature, namely, a necrosis with softening and partial liquefaction, attended by little or no suppurative change. The amœbæ have also been found in the sputum when a liver abscess has ruptured into the lung, as not very infrequently happens.

Relations to the Disease.—It may be stated in the first place that cultures of these amœbæ outside the body have not been obtained. Kartulis announced that he had cultivated the organism on straw infusion, but it is now recognised that his results are erroneous, the amœbæ observed by him being probably derived from the infusion itself. In fact, everything seems to show that the amœbæ in their usual form rapidly disintegrate outside the body, and it is still unknown in what form they survive and lead to the propagation of the disease. The points of distinction between the amœba of dysentery and the ordinary amœba coli, so far as the morphology is concerned, are that the latter is on the whole of smaller size, its protoplasm is more finely granular, and it does not appear to take up red corpuscles, etc., as is the case with the former. The distinction, however, can only be definitely drawn by the result of experiment. Injection of certain quantities of dysenteric stools containing the amœbæ into various animals *per rectum*, has been carried out by different observers, especially by Kruse and Pasquale. In cats, in the majority of cases, a hæmorrhagic enteritis is produced, amœbæ being present in the stools and also invading the mucous membrane of the intestine in the ulcerated areas which are sometimes formed. The deep infiltration of the submucous coat by the amœbæ, which is so characteristic a feature in the human disease, does not occur in these

animals. Not infrequently death follows. Kruse and Pasquale obtained corresponding results when the material from a liver abscess containing amœbæ without any other organisms was injected. In the absence of cultures of amœbæ outside the body, this evidence must be taken as conclusive that the disease produced in cats is really caused by the amœbæ. Similar injections with material containing amœbæ derived from other sources, is unattended by any pathogenic effects of similar nature. Feeding the animals with material containing the amœbæ is much more uncertain in its effect. Quincke and Roos obtained no effects when the amœbæ were administered, but they obtained a fatal result in two out of four cases when the cyst-like forms were given. From this fact they infer that the latter are probably a cystic stage of the former and that the former are destroyed in the gastric contents. This practically forms the only important evidence that a cystic stage of the organism has really been observed. These observers found that the cyst-like bodies were still present even after the material had been kept for two or three weeks.

From the above facts, all of which have received ample confirmation, with the exception of the statements regarding the cyst-like forms, there can be practically no doubt that the amœbæ described are the causes of the form of dysentery with which they are associated. We are still ignorant, however, as to their life-history outside the body, and the modes by which infection is produced. Further, in any case where they act as the primary agent, secondary inflammatory changes in the intestine may be produced by the action of various bacteria.

Varieties of Dysentery.—We have already pointed out that all dysenteric conditions are not of the same nature, and that in certain forms amœbæ are not present. Ogata, for example, investigated an extensive epidemic in Japan without detecting amœbæ. He found, however, in sections of the affected tissues enormous numbers of small bacilli about the same thickness as the tubercle

bacillus, but very much shorter. These bacilli were sometimes found in a practically pure condition. They were actively motile and could be stained by Gram's method. He also obtained pure cultures from various cases and tested their pathogenic effects. They grew well on gelatine at the ordinary temperature producing liquefaction, the growth somewhat resembling that of the cholera spirillum. By injection into cats and guinea-pigs, as well as by feeding them, this organism was found to have distinct pathogenic effects; these were chiefly confined to the large intestine, hæmorrhagic inflammation and ulceration being produced.

Kruse and Pasquale conclude that so far as our present knowledge of the etiology of dysentery goes, there are several varieties which may be arranged as follows. First, the amœbic or tropical dysentery, having the characters as above described; second, the various diphtheritic and catarrhal forms without amœbæ, possibly produced by bacteria of different kinds, but the nature of which has not been fully investigated; third, the Japanese form of dysentery as investigated by Ogata.

Methods of Examination.—The fæces in a case of suspected dysentery ought to be examined microscopically as soon as possible after being passed, as the amœbæ disappear rapidly, especially when the reaction becomes acid. A drop is placed on a slide without the addition of any reagent, a cover-glass is placed over it and the preparation is examined in the ordinary way or on a hot stage, preferably by the latter method, as the movements of the amœbæ are more active and it is difficult to recognise them when they are at rest. Dried films are not suitable, as in the preparation of these the amœbæ become broken down; but films may be fixed with corrosive sublimate or other fixative (*vide* p. 86). In sections of tissue the amœbæ may be stained by methylene-blue, by safranin, by hæmatoxylin and eosin, etc.

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